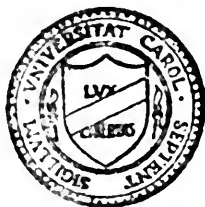




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DIVISION OF MINERAL RESOURCES  
JASPER L. STUCKEY, *State Geologist*

---

BULLETIN NUMBER 41

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# FORSTERITE OLIVINE DEPOSITS OF NORTH CAROLINA AND GEORGIA

*By*

CHARLES E. HUNTER

*Under the Direction of*

H. S. RANKIN

---

PUBLISHED IN COOPERATION WITH THE TENNESSEE VALLEY AUTHORITY



RALEIGH  
1941

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## LETTER OF TRANSMITTAL

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Raleigh, North Carolina  
November 12, 1941

*To His Excellency, HON. J. MELVILLE BROUGHTON,  
Governor of North Carolina.*

Sir: I have the honor to submit herewith, as Bulletin No. 41, a report on "FORSTERITE OLIVINE DEPOSITS OF NORTH CAROLINA AND GEORGIA." This bulletin is being published in cooperation with the Tennessee Valley Authority.

To meet the demands for defense purposes, large quantities of light metals are needed. Since olivine contains a high percentage of magnesium, it is hoped that this report, which shows huge deposits of olivine in North Carolina, will point out a practicable source of this metal for National Defense purposes.

Respectfully submitted,  
R. BRUCE ETHERIDGE,  
*Director.*

## PREFACE

This report entitled "Forsterite Olivine Deposits of North Carolina and Georgia" has been prepared especially to furnish data on the occurrence, amount, mineral associations and chemical quality of the olivine deposits of the areas. The field work was done and the report written by Charles E. Hunter, Associate Geologist, under the direction of H. S. Rankin, Senior Mining Engineer, of the Regional Products Research Division of the Commerce Department, Tennessee Valley Authority.

The purpose of this joint publication with the Tennessee Valley Authority is to present data that demonstrate the presence of large reserves of olivine in western North Carolina and northern Georgia suitable for the production of special refractories and magnesium compounds. The presence of large deposits of olivine adjacent to good transportation facilities in a region where the production of electric power is constantly increasing suggests splendid opportunities for the establishment of industries based on the utilization of these resources.

JASPER L. STUCKEY,  
*State Geologist.*





# FORSTERITE OLIVINE DEPOSITS OF NORTH CAROLINA AND GEORGIA

By CHARLES E. HUNTER\*

Under the direction of H. S. RANKIN¶

## SUMMARY

It is not well known that there occurs in the Southeast a reserve of at least 230,000,000 tons of high-grade forsterite olivine,<sup>1</sup> averaging 48.07 per cent of magnesia, suitable for the production of special refractories and various magnesium compounds. These deposits, because of their occurrence at accessible points and the fact that they contain more magnesium than any other common mineral, have excellent possibilities of being utilized in the development of new important industries in the South.

More than 275 peridotite<sup>2</sup> formations, many of which are dunites,<sup>3</sup> occur in North Carolina and Georgia. These deposits are coexistent with the Blue Ridge Mountains, and outcrop in a belt about 300 miles long. Most of these deposits have been examined during various reconnaissance surveys on associated minerals such as corundum, chromite, nickel, and vermiculite. It was found that a great number of these deposits are in advance stages of serpentinization and steatitization.<sup>4</sup> However, there are about 25 large forsterite olivine deposits, remarkably sound and free from alteration minerals, occurring in a belt 175 miles long and 15 miles wide, ex-

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<sup>1</sup> Forsterite olivine—A mineral composed mostly of magnesium ortho-silicate.

<sup>2</sup> Peridotite—Dark green igneous rock of deep seated origin which consists wholly of ferromagnesian minerals.

<sup>3</sup> Dunite—A variety of peridotite composed mostly of olivine.

<sup>4</sup> Serpentinization and Steatitization—Types of alteration or "decay" common to the peridotite class of rocks.

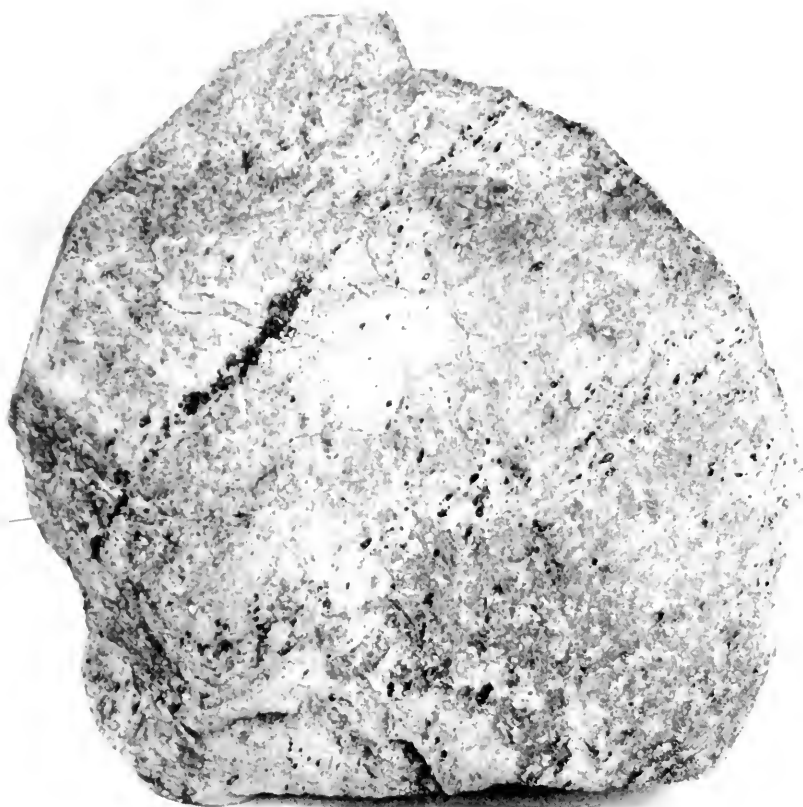


PLATE 1

tending from Watauga County, North Carolina, southwestward to White County, Georgia. Asheville, North Carolina, is about in the center of this belt.

Twenty of the best, largest and most accessible of these forsterite olivine deposits were carefully mapped and sampled. Several known deposits of good olivine

were not mapped and sampled in this belt, because of their occurrence at inaccessible points in mountainous areas, which makes them of little economic value for the production of olivine in the near future. However, they constitute reserves and will be important as sources of olivine when access roads make them economically available.

The deposits mapped consist of dunites and saxonites<sup>5</sup> containing from 60 to 95 per cent coarse-grained friable olivine. The central core, usually about half of the deposit, consists of relatively unaltered olivine; and the outer border of the formation and some faulted zones through the central part are composed of dunite or saxonite partially altered to serpentine and talc. The central or generally unaltered part of the deposits average about 48.07 per cent magnesia and the outer rim, or faulted zone part of the formation ranges between 40 and 48 per cent magnesia. These North Carolina and Georgia forsterite olivine deposits are tremendous in size (one contains 16,550,000 tons of sound olivine and 24,500,000 tons of partly serpentized dunite; the largest contains over 300,000,000 tons of dunite) and remarkably uniform in mineral and chemical composition. A petrographic analysis of a typical sample is as follows: 85 per cent olivine, 10 per cent talc and serpentine, and 5 per cent chromite and others. A chemical analysis of a typical sample is shown in the following tabulation:

MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr Oxides	CaO	Ign. Loss	Total
48.07	40.47	8.68	1.21	0.10	1.21	99.74

Note that in the above table the magnesia is 48.07 per cent and the silica is 40.47 per cent and the absence of large quantities of fluxing ingredients which predisposes

<sup>5</sup> Saxonite—A variety of peridotite similar to dunite but containing crystals of enstatite usually bronzite.

its suitability as a natural refractory in block form or for the production of special refractories. The iron content is 8.68 per cent which makes the fayalite content of the olivine less than 11 per cent as part of the iron is in the chromite.

These deposits are well suited for the quarrying of high-grade olivine, since most of them, being more resistant to erosion than the surrounding area, stand up as hills of relatively sound formation. All of the twenty large deposits mapped in this survey are accessible to rail or truck transportation. Dark Ridge, Addie and Webster, among the largest and best deposits, are crossed by branches of the Southern Railway. The Day Book and Newdale deposits occur less than five miles from Clinchfield (C.C.&O.) railroad stations. The material occurring in the North Carolina and Georgia forsterite olivine deposits is of such uniform character that, if occasion should arise, it could be used in a centrally located plant. Based upon carefully made calculations it is estimated that there occur within the area 1,000,000,000 tons of dunite containing more than 40 per cent magnesia and 230,000,000 tons of "quarrrable" high-grade olivine averaging 48.07 per cent magnesia. It is estimated that it will cost \$0.60 to \$1.50 per ton to quarry, crush, and screen this material depending upon the size ranges of aggregate desired.

#### INTRODUCTION

Olivine, one of the major undeveloped mineral resources of the Southeast, occurring in North Carolina and Georgia, was known as early as 1875 and described as "chrysolytic sandstone."<sup>6</sup> Later, the olivine deposits were recognized as dunites and described as such by Pratt and Lewis in their report, "Corundum and the Peridotites of Western North Carolina."<sup>7</sup> The mineral

<sup>6</sup> W. C. Kerr, State Geologist of North Carolina, Report, Geologic Survey of North Carolina, *Vol.* No. 1 (1875) p. 129.

<sup>7</sup> Joseph Hyde Pratt and Joseph Volney Lewis, "Corundum and the Peridotites of Western North Carolina," North Carolina Geological Survey, *Vol.* I (1905).

olivine is a common constituent of igneous rocks, which originate from deep within the earth. The mineral, usually olive green or pale yellow in color (hence its name), often occurs in small irregularly outlined crystals, and, more often, in grains similar in size and shape to those of granulated sugar. It is a magnesium iron orthosilicate.<sup>8</sup> The North Carolina and Georgia variety contains detectable amounts of nickel and chromium. An important characteristic of the mineral is that it contains 75 to 95 per cent forsterite (pure magnesium silicate), which is a superior basic refractory<sup>9</sup> with a melting point of 1890° C. The best grades contain about 30 per cent magnesium, more than any other magnesium-bearing mineral occurring in such large quantities.

In 1933 the experimental use of a small amount of North Carolina olivine as a basic refractory in the eastern steel industry created some interest in these deposits. The increase in production has been slight, largely because of the difficulty of obtaining satisfactory shapes for refractory work. Most of the consumption has been in the form of quarry-mined blocks. The present annual output from the TVA region is below 10,000 tons, which until recently was used entirely for refractory purposes. Some olivine is now being used in experimental production of magnesium sulphate.

These olivine deposits constitute a practically inexhaustible reserve of a mineral uniform in composition. It was determined from the survey just completed that there is available from 20 readily accessible deposits 230,000,000 tons of unaltered olivine, containing more than 45 per cent magnesia,<sup>10</sup> and one billion tons of partially serpentinized dunite<sup>11</sup> composed of 50 per cent or more olivine averaging about 44 per cent magnesia.

<sup>8</sup> Magnesium-iron orthosilicate— $2(\text{Mg,Fe})\text{O} \cdot \text{SiO}_2$ .

<sup>9</sup> Basic refractory—material with high resistance to heat and certain types of slag.

<sup>10</sup> Magnesia—magnesium oxide.

<sup>11</sup> Serpentinized dunite—rock composed principally of olivine; part of the olivine shows signs of alteration or "decay."

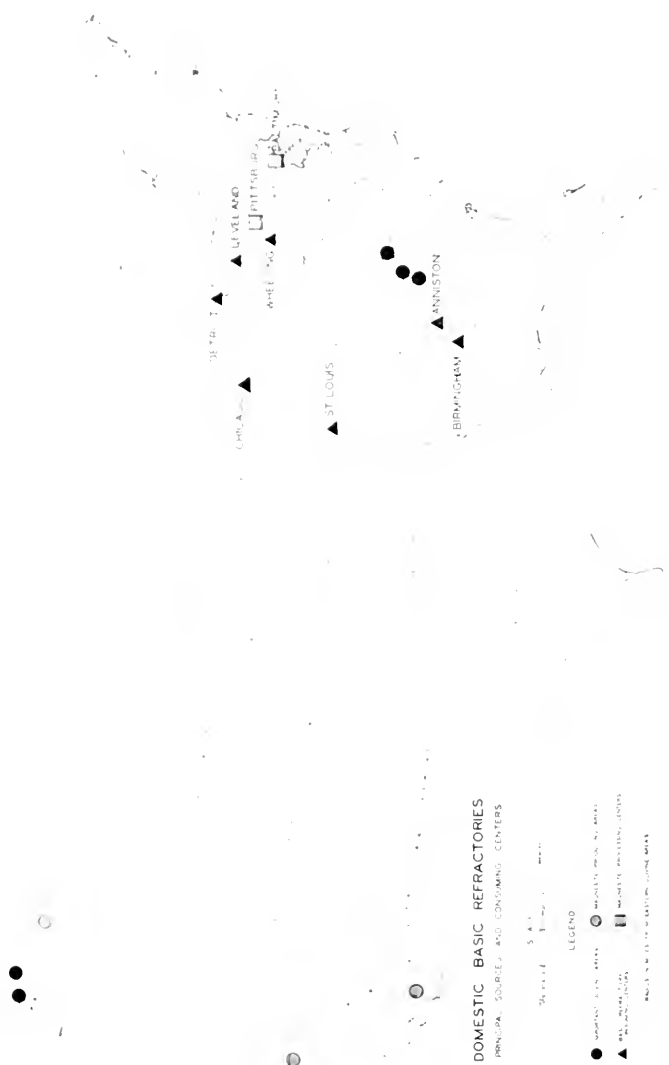


PLATE 2

Only those reserves containing more than 40 per cent magnesia were considered in these estimates. The reserves considered are only those occurring above the local drainage level. Careful sampling and analyses show great uniformity of magnesium and iron content throughout the area.

The location of these deposits within 500 miles (see Plate 2 and Plate 3) of important metallurgical centers favors the possibility of their development in the near future for the production of superior basic refractories. In addition, these olivine deposits are surrounded by such hydroelectric developments as Tennessee Valley Authority, Nantahala Power Co. (Aluminum Co. of America), Carolina Power & Light Co., and Duke Power Co. These companies can furnish low-cost electricity for processing the olivine into forsterite<sup>12</sup> and other refractories, into magnesium compounds, and last, but probably most important, into metallic magnesium.

The potential importance of these olivine deposits in the Tennessee Valley region has not perhaps been fully realized. During times of war or national preparedness, the steel industry runs at capacity. One of the important problems in steel production is the supply of satisfactory basic refractory furnace linings. Magnesite,<sup>13</sup> extensively used in the eastern and southern steel industries, is obtained either by importation or from the Pacific Coast states. In war times the supply of imported magnesite cannot be relied upon, and the domestic material has to be transported from the West Coast (see Plate 2). These large reserves of olivine, a basic refractory material occurring so near the steel plants, may be of great importance in the national defense.

The increased demand for magnesium in airplane construction, general light-weight metallic uses, military flares, and incendiary bombs requires that magnesium

<sup>12</sup> Forsterite—an important refractory magnesium silicate mineral.

<sup>13</sup> Magnesite—The mineral magnesium carbonate ( $MgCO_3$ ).

production in the United States be greatly expanded. Olivine, because of its tremendous, low-cost reserves, and high magnesium content, offers great potentialities as an ore of the metal. Active research, by the Tennessee Valley Authority, is now under way to develop a process for utilizing the olivine as an ore of magnesium.



PLATE 3

### HISTORY OF DEVELOPMENT

Olivine and forsterite refractories were first commercially used in America during 1933.<sup>14</sup> Since that

<sup>14</sup> Fred A. Harvey and Raymond E. Birch, "Olivine and Forsterite Refractories in America," *Industrial and Engineering Chemistry*, January, 1938, p. 28.



date the amount produced has increased slowly, with most of the use confined to experimental purposes. The forms in which it has been used are shaped crude olivine blocks, crushed bonded crude olivine, and forsterite produced from olivine, none of which have been said to be entirely satisfactory industrially.

#### REVIEW OF RESEARCH

One of the earliest technical reports issued on olivine in the United States was by Heindl and Pendergast.<sup>15</sup> Part of their summary states: "The results indicated that the material from North Carolina was sufficiently refractory to heat [and sufficiently resistant to some types of slag] to warrant its use as a special refractory. Bricks were easily made from run-of-mine material and proved satisfactory in the few physical tests to which they were subjected."

"The Production of Unfired and Fired Forsterite Refractories From North Carolina Dunites," by Greaves-Walker and Stone, reviews previous publications on olivine refractories by others, and presents additional data obtained by them at the North Carolina Engineering Experiment Station.<sup>16</sup>

Harvey and Birch have presented well the case of the new refractory in their article, "Olivine and Forsterite Refractories in America."<sup>17</sup> Goldschmidt, one of the pioneers in research in olivine refractories, has written a review on its use in Europe.<sup>18</sup>

#### RESEARCH IN PROGRESS

During 1940 and 1941 the Electrotechnical Laboratory at the Norris Station of the U. S. Bureau of Mines has worked on the development of a forsterite firebrick

<sup>15</sup> Olivine as a Refractory, U. S. Bureau of Standards Research Paper, RP 645 (February 1934), p. 222.

<sup>16</sup> Bulletin No. 16 (September 1938), Engineering Experiment Station, State College, Raleigh, North Carolina.

<sup>17</sup> Industrial and Engineering Chemistry, January 1938, p. 27.

<sup>18</sup> V. M. Goldschmidt, "Olivine and Forsterite Refractories in Europe," *Industrial and Engineering Chemistry*, January 1938, p. 32.

from olivine melted in an electric furnace. The forsterite produced is nearly pure and it has promise of becoming a remarkably high melting basic refractory of potentially wide application.

The results of recent research being carried out by the staff of the Regional Products Research Division of the TVA on magnesium chloride production from olivine have been encouraging. This process, if the experiments now under way prove successful, would make olivine available as a low-cost ore for the production of magnesium metal since the methods for making the metal from the chloride are well established.<sup>19</sup>

#### PRESENT COMMERCIAL USE

For several years, North Carolina olivine has been used in the construction of semisloping back walls in open hearth furnaces, though the greatest use has been in furnace repair. The firm of Gillis and Pawel (Olivine Products Cpn.) of Webster, North Carolina, has recently established a commercial plant for making magnesium sulphate<sup>20</sup> from olivine. Their process, based on several years' research, consists essentially of digesting crushed olivine in sulphuric acid, separating the iron, and crystallizing the magnesium sulphate from solution. This is probably the first plant using olivine as a source of material for the production of magnesium salts.

#### FUTURE USE OF OLIVINE

Forsterite produced from olivine has an excellent opportunity, because of its refractoriness and place of occurrence, to become an important factor in the basic and special refractory industries of the country. In addition, the use of forsterite lining in cement kilns offers

<sup>19</sup> A summary of research on magnesium from olivine was presented by E. C. Houston and H. S. Rankin as a paper entitled "Olivine as a Source of Magnesium," delivered at a meeting of the Industrial Minerals Division of the American Institute of Mining & Metallurgical Engineers, held at Rolla, Mo. on October 24, 1941.

<sup>20</sup> Magnesium sulphate—used in rayon, textile, and tanning industries, southern bright leaf tobacco fertilizer, and pharmaceuticals.

great promise because of its long life and other desirable properties.

Olivine, because of its high magnesium content and low cost, offers possibilities for the production of various magnesium compounds, the metal, and special fertilizers.

#### **ACKNOWLEDGMENTS AND FIELD WORK**

This report presents data obtained in an economic geological field survey by Charles E. Hunter, Samuel D. Broadhurst, and Gilbert C. Robinson between July 1 and September 15, 1940. The maps used in the report were prepared by Samuel D. Broadhurst.

Acknowledgment for constructive criticism and helpful suggestions in preparing this report is made to: Dr. Frank L. Hess, Principal Mineralogist, U. S. Bureau of Mines, Eastern Experiment Station, College Park, Maryland; Dr. Jasper L. Stuckey, State Geologist, Raleigh, North Carolina; Dr. Hewitt Wilson, Supervising Engineer, Electrotechnical Laboratory, U. S. Bureau of Mines, Norris, Tennessee; and Dr. Geoffrey W. Crickmay, Professor of Geology, University of Georgia.

#### **REGIONAL GEOLOGY**

The western part of North Carolina and northern Georgia in which the olivine deposits occur is a part of the great belt of crystalline rocks that is co-extensive with the Appalachian Mountain system. This area contains such peaks as Mount Mitchell with an elevation of 6,684 feet. The mountains in the area, for the most part, were formed by differential weathering; therefore the individual spurs and tops do not have a definite pattern. However, the trend of the ranges as a whole is southwest-northeast.

Pratt and Lewis have made a rather thorough and detailed study of the geology of western North Carolina and little can be added in a general way to their excellent description of the geology of the area. So liberty is here

taken to quote parts of their publication, "Corundum and Peridotites of Western North Carolina."<sup>21</sup>

On account of their complex structure, and highly crystalline character, these rocks [of Western N. C.] are generally considered to be Archean Age. . . . The principal constituent of the system is banded gneiss, which includes many masses of granitic and other distinctly igneous rocks [diorite and hornblende schist] and which often, through higher development of lamination, passes into mica-schist and amphibole-schists.

The gneisses have been usually considered, in part, sedimentary rocks that have lost their original characteristics (with the possible exception of bedding in some cases) in the great earth movements and other metamorphosing agencies to which they have been subjected. Some of them are undoubtedly granites, diorites and other igneous rocks that have been sheared or squeezed by some agencies, and transitions from the massive to the laminated forms have often been observed.

Lamination is often developed where no such original structure existed, as in the sheared massive rocks referred to above. It is known that such structure produced by movement in the mass of rock may, and often does, obliterate whatever original structure may have been present; so that a sedimentary rock thus mechanically laminated and at the same time thoroughly crystallized would no longer show its original stratification. The new structural planes may in certain cases correspond with bedding, but often they do not; and it is frequently impossible even to distinguish between gneisses and schists of igneous origin and those produced by the extreme metamorphism of sedimentary beds. The strikes and dips observed in this region are in all cases those of secondary lamination planes, and have no reference to stratification nor to any particular theory of origin.

In some regions the gneisses present several characters that point strongly to a sedimentary origin. They contain limestones in considerable amount at the forks of Caney Fork of Tuckaseegee River, in Jackson County, and on the eastern slopes of Onion Mountain and the headwaters of Ellijay Creek, in Macon County. These limestones are often

<sup>21</sup> North Carolina Geological Survey; *Fol.* 1 (1905), p. 24.

more or less graphitic. There are also frequent streaks and disseminated scales of graphite in the mica-schists . . . these, together with the extremely variable character of the gneisses in many regions and their frequent rapid passing into mica-schist and sometimes into quartz-schist, would seem to justify the reference of a large part of the series to a sedimentary origin.

In recent years the theory of sedimentary origin for part of the gneisses and schists has been strengthened by the finding of additional interbedded limestones and interfingering quartzites with the gneisses and schists, such as the occurrences in the vicinity of Lake Toxaway, Bandana and Marshall, North Carolina, and Hollywood, Georgia.

The prevailing strike of the lamination planes in the gneiss of western North Carolina is about N. 30 deg. E, and the prevailing dip is at a high angle toward the southeast. Very frequently local variations occur, especially in the dip, and the prevailing southeasterly dip will become vertical within an outcrop covering only a few feet and, tipping over, will pass into a northwesterly dip. All stages occur from these local variations in the dip and strike to the most complex gnarled and contorted forms. In general, the lamination has suffered most deformation in the immediate vicinity of igneous intrusions and the forces that produced the contortions doubtless formed simultaneously the fissures into which the massive rocks were injected.

This gneissic belt of the mountain region, which averages about 35 miles wide, is bordered on the West and East by two belts of partially metamorphosed sedimentary rocks that are considered by Mr. Arthur Keith, of U. S. Geological Survey, to be of lower Cambrian Age. . . . This formation consists of a lower series of sandstones and conglomerates and an upper series of shales and limestones, the whole lying unconformably on the gneisses.

This belt of gneiss above described is cut by a great many narrow strips and small lenticular masses of basic magnesium rocks, chiefly peridotites, which rarely exceed a mile or two in length. As far as has been observed, these rocks are nowhere intimately associated with igneous rocks of the granitic type. . . . These basic magnesium rocks of North

Carolina [and Georgia] intersect no formations of later age than the supposedly pre-Cambrian<sup>22</sup> gneisses.

The peridotites and related rocks form disconnected masses arranged in a line or series of parallel lines that coincide approximately in direction with the strike of the gneissic lamination.<sup>23</sup> They almost invariably have a sheath of some schistose<sup>24</sup> mineral developed along their borders, so that there is rarely an absolute contact between [them and] the normal gneiss.

The North Carolina and Georgia peridotites are intruded into the central part of a great geanticline<sup>25</sup> and many of these intrusions are thought to have been a part of a volcanic system once active in pre-Cambrian times. Some of the dunites and saxonites (defined on following page) now exposed may be part of an ancient deep seated volcanic system. These formations vary in extent of surface outcrop, from 1500 square feet (Otto deposit in Macon County, N. C.), to one-half square mile (Buck Creek Deposit, Clay County, N. C.). All the deposits extend downward several hundred feet, and the largest probably extend downward to great depths.

## GEOLOGY OF PERIDOTITES

### DUNITES AND SAXONITES

The western North Carolina and northern Georgia olivine deposits can be classified as dunites and saxonites. The dunites are composed of essentially pure olivine with accessory primary minerals such as chromite or picotite,<sup>26</sup> while the saxonites are practically the same except that they contain primary bronzite<sup>27</sup> (see Plates 4 and 5). In many cases the bronzite has been altered to talc. The dunite bodies are more numerous and usually larger than

<sup>22</sup> Pre-Cambrian—a very early and old geologic age.

<sup>23</sup> Gneissic lamination—light and dark-colored minerals arranged in bands in the rock.

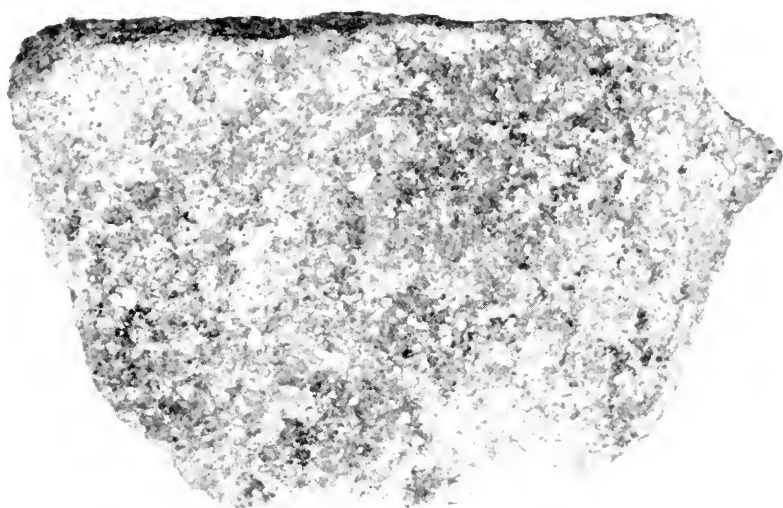
<sup>24</sup> Schistose—scaly minerals such as vermiculite or mica—forming a platy surface cross section.

<sup>25</sup> Geanticline—a fold of great magnitude (more than 10 miles in diameter) in the rocks of the earth's outer crust zone.

<sup>26</sup> Picotite—a chrome spinel mineral, chiefly chromium oxide.

<sup>27</sup> Bronzite—Iron-bearing variety of the mineral enstatite with a bronze luster.

## PLATE 4



### A. COARSE TEXTURED DUNITE

Dunite consisting essentially of unaltered, dark green olivine crystals which average about 1 mm. in diameter. Minute crystals of primary chromite are disseminated throughout the dunite. Natural size.



### B. COARSE TEXTURED SAXONITE

Saxonite composed of partly altered, dark green olivine, bronzite, and chromite. The olivine crystals average about 1 mm. in diameter and usually show shattering due to serpentinization around the borders. The bronzite crystals are partly altered to talc. Natural size.

the saxonites, which frequently are found in contact with, or surrounded by, dunite.

Olivine deposits now exposed at the surface by erosion were probably formed (crystallized and cooled) at a depth greater than ten miles below the surface at the time of their injection. This depth of intrusions is substantiated by the structure of the region, and the fact that erosion during geological times has removed rocks and sediments from the area totaling approximately ten miles in thickness. Grout states that ultra-basic igneous rocks, such as dunites, are deep-seated in formation.<sup>28</sup>

The country rock, surrounding these intrusions, is in most instances hornblende<sup>29</sup> gneisses and schists. A direct relationship between the hornblende and peridotite formations is evidenced by the fact that olivine grains have been found in some hornblende formations adjacent to the dunites. Such a relationship was observed in Yancey and Clay Counties, and suggests that the two basic igneous formations probably originated from the same parent magma occurring at a much greater depth. The peridotites (olivine-bearing rock) are apparently the younger of the two, because in many places, Webster for example, large and small hornblende inclusions were noted surrounded by dunite. The contact between the inclusions and the dunite is seldom sharp, because a fringe of impure vermiculite and actinolite occurs around the hornblende inclusion which indicates the metamorphic action of the peridotite intrusion.

The peridotites with which this report is concerned are of the dunite and saxonite type consisting of more than 60 per cent olivine. These intrusions can be subdivided into two structural types, the most common of which is a lens-shaped intrusion with the long axis

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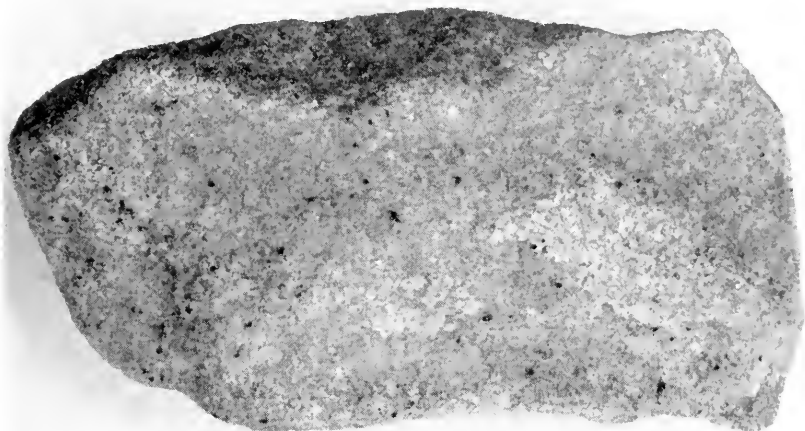
<sup>28</sup> Frank F. Grout, "Petrography and Petrology" (New York: McGraw-Hill Book Company, Inc., 1932) p. 147.

<sup>29</sup> Hornblende—a complex black mineral composed mainly of magnesium, calcium, aluminum, and iron silicate.



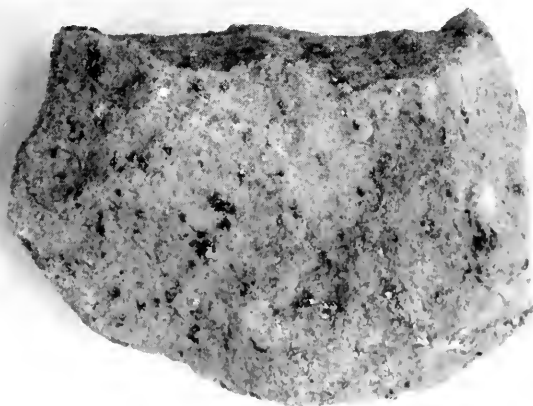
parallel to the regional schistosity, and the other is of the ring-dike or crescent type. Similar olivine occurs in both types, but the internal structural features are somewhat

## PLATE 5



## A. FINE GRAINED DUNITE

This dunite consists essentially of unaltered, light green olivine and disseminated minute crystals of primary chromite. The olivine grains average about 0.2 mm. in diameter. Natural size.



## B. FINE GRAINED SAXONITE

A partly altered saxonite consisting of light green olivine, chromite, bronzite, and talc. The olivine grains average less than 0.2 mm. in diameter, and the bronzite crystals average more than 10 mm. in diameter. Some of the bronzite is entirely altered to talc. The specimen shows a slight amount of chloritization. Natural size.

different. In the lens-shaped type the cooling joints and occasional faults are the most prominent features. In the ring-dike type, the most noticeable feature is the parallel lamination which on a weathered surface has the appearance of thin-bedded sandstone. In all cases this lamination is roughly parallel to the contact of the olivine formation and to the schistosity of the country rock.

Segregations of various types of olivine are more pronounced in the ring-dike than in the lens-shaped formations. This difference is probably due to later basic intrusions which have undergone little alteration, and to structural features which have protected certain areas from hydro-thermal solutions.

#### ASSOCIATED MINERALS

The dunites and saxonites contain accessory minerals such as chromite, picotite, bronzite, and many others.<sup>30</sup> Olivine accounts usually for more than 60 per cent of the formation and most of it consists of 80 per cent forsterite, 11 per cent or less fayalite,<sup>31</sup> and the remaining 9 per cent or less of other magnesium minerals.<sup>32</sup> In some of these deposits chromite is a conspicuous mineral occurring as well-formed disseminated crystals throughout the dunite rock, or as small lenses and veins of massive chromite surrounded by friable and granular olivine. At some places, such as a part of the Webster ring-dike<sup>33</sup> series, the chromite makes up as much as 25 per cent of the dunite.<sup>34</sup> The secondary magnesium minerals derived from olivine include a wide variety of hydrated minerals.<sup>35</sup>

At a few places, especially near Webster and Democrat, N. C., nickel silicate veins, nickeliferous clay, and

<sup>30</sup> Pratt and Lewis, *op. cit.*, p. 29.

<sup>31</sup> Fayalite—an iron silicate mineral.

<sup>32</sup> R. A. Heindl and W. L. Pendergast. "Olivine as a Refractory," U. S. Bureau of Standards *Research Paper* 645, (February 1934), p. 219.

<sup>33</sup> Ring-dike—a geologic structure circular or elliptical in shape.

<sup>34</sup> Edwin C. Eckel, Charles E. Hunter, and Philip W. Matrocks, "Iron, Chromite, and Nickel Resources of the Tennessee Valley Region," Tennessee Valley Authority, Geologic Division, *Bulletin* 10 (1938) p. 19.

<sup>35</sup> Pratt and Lewis, *op. cit.*, pp. 74 and 112.

nickel-bearing vermiculite are rather conspicuous in the dunite.<sup>36</sup> These veins seldom exceed two feet in width but sometimes they are found rather closely spaced; that is, occurring only a few feet apart and separated by dunite, which is cut by many tiny veinlets of a harder nickel silicate mineral, genthite. In the Webster area the nickeliferous veins are reported to average about 5.34 per cent NiO, and the altered dunite and serpentine associated with these veins to average about 1.50 per cent NiO.<sup>37</sup> Some nickel is detectable in all the olivine deposits and many of them average more than 0.25 per cent nickel. Vermiculite occurs with all the dunite formations both as fringe veins in contact with the country rock and as interior veins in joints and faults within the olivine body.<sup>38</sup> These veins vary in thickness up to 15 feet, the average being about three feet. Corundum is a common accessory mineral. In the Ellijay area of Macon County, N. C., vermiculite occurs rather abundantly with the olivine-bearing formations. However, it is usually found in commercial quantities only in those formations through which pegmatite<sup>39</sup> solutions (hot silica-bearing) have passed. Many of the dunite bodies offered structural weaknesses ideal for the entering of intrusions and, therefore, contain numerous small pegmatites with highly altered dunite on each side.

Many of the dunites contain veins and seamlets of anthophyllite asbestos. The olivine associated with this asbestos is usually of an inferior quality because of the occurrence of a high percentage of chlorite and talc, developed along with the anthophyllite, which lowers the magnesium content and refractoriness. In addition, the

<sup>36</sup> Eckel, Hunter, and Mattocks, *op. cit.*, p. 22.

<sup>37</sup> G. W. Pawel, "Nickel in North Carolina," *Engineering and Mining Journal*, October 1939, p. 35.

<sup>38</sup> Charles E. Hunter, Philip W. Mattocks, and Others, "Vermiculite and Bentonite of Tennessee Valley Region," Tennessee Valley Authority, Geologic Division; *Bulletin 5* (1936) p. 3.

<sup>39</sup> Pegmatite—an igneous intrusion composed of solutions carrying acid minerals such as quartz and feldspar.

exteriors of individual olivine grains are partly altered to secondary magnesium minerals which, in most cases are inert to acids; consequently the material is rendered undesirable for use as a source of magnesium in a chemical process.

These associated minerals offer possibilities as important by-products in any substantial olivine production. Such minerals as vermiculite, talc, asbestos, chlorite, chalcedony, corundum and some chromite and nickel ore could be produced at the quarry along with the olivine. However, much chromium and nickel would be obtained from the residue and solution after the magnesium has been taken out of the olivine by a chemical process.

#### SERPENTINIZATION

The olivine from most of the deposits shows some degree of serpentinization under the microscope and in some cases the serpentinization has been so complete that it is difficult to find remaining a remnant or skeleton olivine crystal. A widespread misconception is the belief that the serpentinization in the dunite and saxonite is a surface phenomenon due to weathering. This conception is not substantiated by field evidence. Pratt and Lewis recognized that the serpentinization was due to hydrothermal action which took place on the olivine many millions of years before the deposits were exposed by erosion. They presented thorough and convincing data on deep-seated serpentinization of the North Carolina dunites in their excellent report, "Corundum and Peridotites of Western North Carolina." Pratt and Lewis state: "Serpentinization, therefore, is believed to be a process that can take place only below the depth of active weathering . . . . On this hypothesis serpentine could exist at the surface only where a certain amount of overlying rock has been decomposed and removed after the alteration of the peridotite [dunite] into serpen-

tine.”<sup>40</sup> G. W. Bain recently reviewed previous papers on serpentization and presented additional data of his own. Part of his paper is here quoted.<sup>41</sup>

These important contributions to the literature on origin of serpentine indicates four modern schools of thought. First, Benson, Arshinov and Merenkov, and Hess would invoke the process of autometamorphism—alteration by a late stage portion of the ultrabasic magma while it is in the process of crystallization. Second, Graham and Dresser would attribute the change to attack of a granitic differentiation extract of the original ultrabasic, after crystallization of the olivine. Third, Cairnes and Cooke would interpose a period of tectonic movement between crystallization of the ultrabasic and serpentization, but they refrain from ascribing an origin to the solutions causing the change. Fourth, Foslie and Du Rietz seemingly concur with Cairnes and Cooke but deny any relationship between the original ultrabasic magma and the solutions causing the change.

Bain observed that fault-sheared zones were completely serpentized while the bordering less disturbed saxonite was only slightly serpentized. He is of the opinion that much of the serpentization (in Vermont) is due to solutions originating from without the formation.<sup>42</sup>

No one mode of serpentization was solely responsible for the serpentine developed in the dunite and saxonite occurring in North Carolina and Georgia. Field evidence shows that a combination of the serpentization processes was active in these deposits. Alteration by autometamorphism and later by granitic or pegmatitic intrusions are the two principal and most common types of serpentization found in these deposits.

There is little doubt that all the olivine deposits (in the area covered by this report), when first formed, were either dunite or saxonite of a very similar and uniform mineralogical and chemical composition (see Plate 6).

<sup>40</sup> Pratt and Lewis, *op. cit.*, p. 119.

<sup>41</sup> G. W. Bain, "Serpentinization of Vermont Ultrabasics," *Bulletin of Geological Society of America*, Vol. 47 (1936) p. 1964.

<sup>42</sup> *Ibid.*, p. 1968.

But immediately after the magma was intruded into the country rock, the olivine began to undergo alteration of the type known to geologists as being "cooked in its own juices." That is, during the cooling period of the olivine magma, the entire formation was subjected to the vapors

### DESCRIPTION OF PLATE 6

Showing photomicrographs of thin sections of dunite illustrating various stages of alteration of olivine<sup>13</sup>.

Figure 1. Dunite from the Railroad cut (Dark Ridge Deposit) 2 miles west of Balsam Gap, Jackson County, N. C. A photomicrograph in ordinary light, magnified 12 diameters. A typical granular dunite, showing only the slightest trace of alteration to serpentine. Thin section No. W11.

Figure 2. Dunite from Webster, Jackson County, N. C. A photomicrograph in ordinary light, showing the beginning of serpentinization along the borders of the olivine grains.

Figure 3. Dunite, Webster, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Shows an advanced stage in the alteration of the olivine to serpentine. Some of the olivine grains are darkened on the borders by the segregated iron oxides. Thin section No. W1.

Figure 4. Dunite, Webster, N. C. A photomicrograph in ordinary light, magnified 18 diameters. Similar to Fig. 3, except in the larger amounts of the iron oxides segregated along the borders of the olivine remnants. Thin section No. W9.

Figure 5. Dunite from Cane Creek, 5 miles northeast of Webster, N. C. A photomicrograph in ordinary light, magnified 14 diameters. Shows the typical structure of laminated dunite, with alternating layers of sheared and unsheared granular olivine. Only a trace of serpentinization. Thin section No. W23.

Figure 6. Dunite from 5 miles northeast of Webster, N. C., on the road from Webster to Hall. A photomicrograph in ordinary light, magnified 18 diameters. Shows dunite altered to chlorite in radiating tufts, with granules and irregular aggregates of magnetite. Small unaltered remnants of olivine are scattered throughout the field. Thin section No. W5a.

<sup>13</sup> Plate No. 6 and description thereof taken from Joseph Hyde Pratt and Joseph Volney Lewis, "Corundum and the Peridotites of Western North Carolina," North Carolina Geological Survey, *Bull.* 1, pages 434 and 435.

PLATE 6

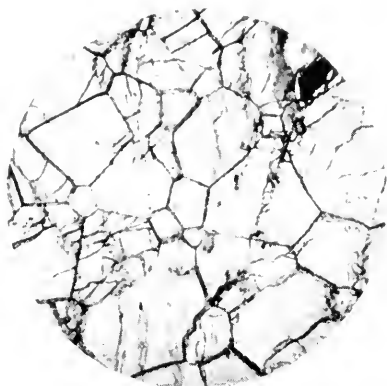


FIG. 1.

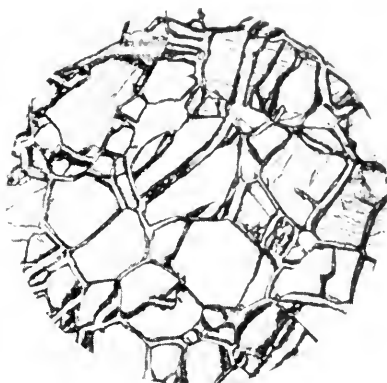


FIG. 2.

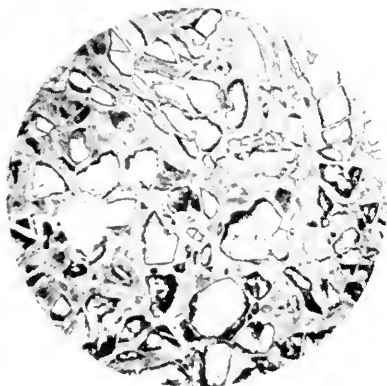


FIG. 3.

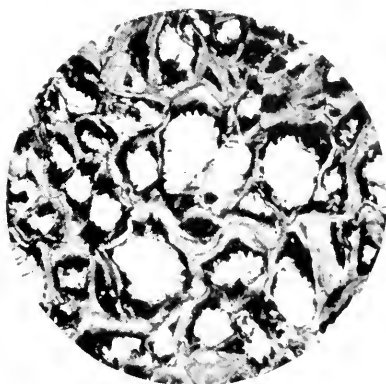


FIG. 4.



FIG. 5.



FIG. 6.

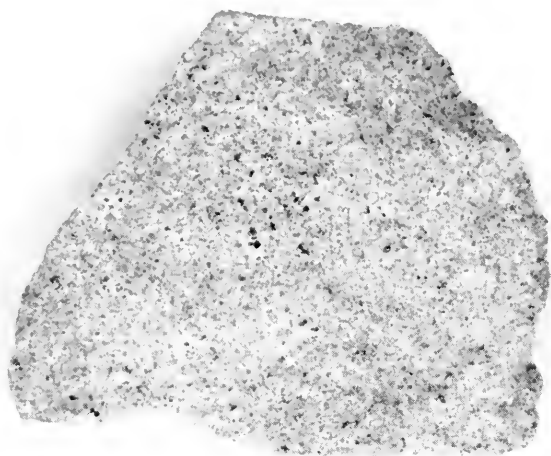
## DESCRIPTION OF PLATE 7

- A. Fine-grained dunite made up of light green olivine with disseminated chromite. The olivine grains average about 0.2 mm. in diameter and are entirely surrounded by yellowish serpentine. The chromite crystals are well defined octahedrons averaging about 0.5 mm. in diameter and show no indications of being altered. Natural size.
  - B. Dark gray dunite made up of interlocking olivine crystals which average about 2 mm. in diameter. As seen in thin section, serpentine forms about 15 per cent of the rock and is found to penetrate the olivine crystals. Chromite is sparingly present, and as seen microscopically, occurs as remnant crystals partially replaced by chlorite. Natural size.
  - C. A fine-grained dunite consisting of light green olivine crystal remnants enclosed by brown and gray serpentine which imparts a dark color to the rock. This dark, olive-drab color is characteristic of olivine that has undergone hydrothermal serpentinization. Natural size.
  - D. A representative specimen of medium-grained dunite consisting of pale green olivine partially altered to serpentine. Note the vein of secondary dolomite with small enclosed crystals of chromite. Natural size.
- 

and solutions being produced during the time of crystallization and cooling of the intrusion. After the olivine bodies cooled, many of them underwent repeated periods of serpentinization by invading pegmatite solutions (see Plate 7, Fig. C). So it is no wonder that all conceivable stages of serpentinization are represented in the various olivine deposits in the area. In most cases, however, parts of the olivine formations were protected by faults from the solutions and have remained relatively sound and free from serpentine growth. This is evidenced by the fact that the rising solutions were confined principally to the fault zones, and did not extend outward from them to any great extent into the main body of the deposit.



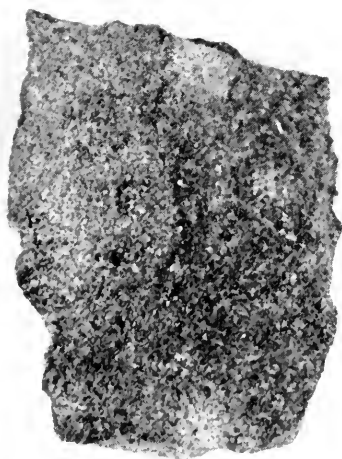
PLATE 7



A.



B.



C.



D.

The Balsam Clay and Dark Ridge olivine deposits described in detail on page 670 show comparatively little serpentinization. However, both of these deposits have undergone but metamorphism; that is, they were attacked by a fluid liberated during the crystallization period of the magma. Alteration from permatitic or granitic intrusions are almost entirely absent in these two deposits. Thus, these two deposits are examples of olivine deposits which have undergone a minimum amount of serpentinization. The Democrat dunite (described in detail on page 61) is cut by several large permatites and almost the entire formation is highly serpentinized. Thus, it is an example of a formation which has undergone a great deal of both types of serpentinization.

#### STEATITIZATION

Steatitization is the mode of alteration common around the border zones of dunites and saxonites. This type of alteration is brought about by attacking siliceous solutions which change the dunite into impure talc soapstone. It is later than serpentinization and is produced by siliceous solution originating from without the formation. This method of alteration is of little importance because of its limited extent, usually confined to the borders of the formation and therefore should not interfere with the production of olivine.

#### CONTACT METAMORPHISM

In discussing the origin of the dunites, Greaves-Walker and Stone, in their publication, state: "It is more probable that the accumulated crystals of olivine, formed by sinking from a complex magma, were intruded into surrounding rock while in a more or less plastic state, in which case the temperature existing would have been reasonably low and, therefore, the contact zone would be comparatively narrow." They follow this

statement with: "An example of this condition has been noted in the biotite schist underlying the dunite at Balsam, N. C. The schist contains large amounts of plagioclase and is not altered to a depth of more than two inches at the contact with the dunite."<sup>1</sup> Others have made similar statements trying to explain the absence of contact metamorphism. For example, Hess states: "The absence of contact metamorphism around basic intrusions favors the hypothesis [relating to serpentinization] that the solutions were moving rather from the country rocks into the magma than vice versa."<sup>2</sup> No doubt shortly after the olivine was intruded the surrounding country rock did show contact metamorphism. However, all signs of this contact metamorphism have long since been obliterated by the schistosity<sup>3</sup> developed in the rocks during the several periods of great earth movements which the area has undergone since the first olivine intrusions. Also there is clear evidence at many of the deposits that there has been much fault displacement along the contacts, so it is rare indeed that the dunite is now in contact with the rock into which it was intruded. This condition is well illustrated in the central western part of the Day Brook dunite-saxinite formation (see Plate 11). Here the dunite is in direct contact with a large lens of the Spruce Pine Alaskite<sup>4</sup> which is a relatively recent acid (high silica) intrusion, and there is no sign of serpentinization due to the presence of the alaskite, which proves that the dunite and alaskite have been brought together by faulting.

<sup>1</sup> *ibid.*

<sup>2</sup> H. H. Hess, "The Problem of Serpentinization and the Origin of the Alkaline Rocks of the Hawaiian Islands," *Astrophys. and J. Geol. Soc. America*, Vol. 52, No. 1, 1939, p. 100.

<sup>3</sup> Serpentinization is the natural growth of a rock in which the silicate minerals have been altered in the same place.

<sup>4</sup> Charles E. Hartshorn, "Spruce Pine Alaskite, N. C.," *Proceedings of the American Ceramic Society*, March 1947, p. 125.

### WEATHERING

The dunites and saxonites, composed almost entirely of forsterite olivines that have not undergone serpentinization, do not weather by decay as is customary with most rocks. Forsterite olivine is rather soluble and goes into solution in a manner similar to that of a pure limestone; thus the surface of an outcrop is covered by a thin coat of insoluble residue under which there is sound olivine. However, olivine formations are more resistant to mechanical erosion than the surrounding country rock and thus usually stand up as hills in a mountainous country where the rain fall is heavy and the erosion is rapid.

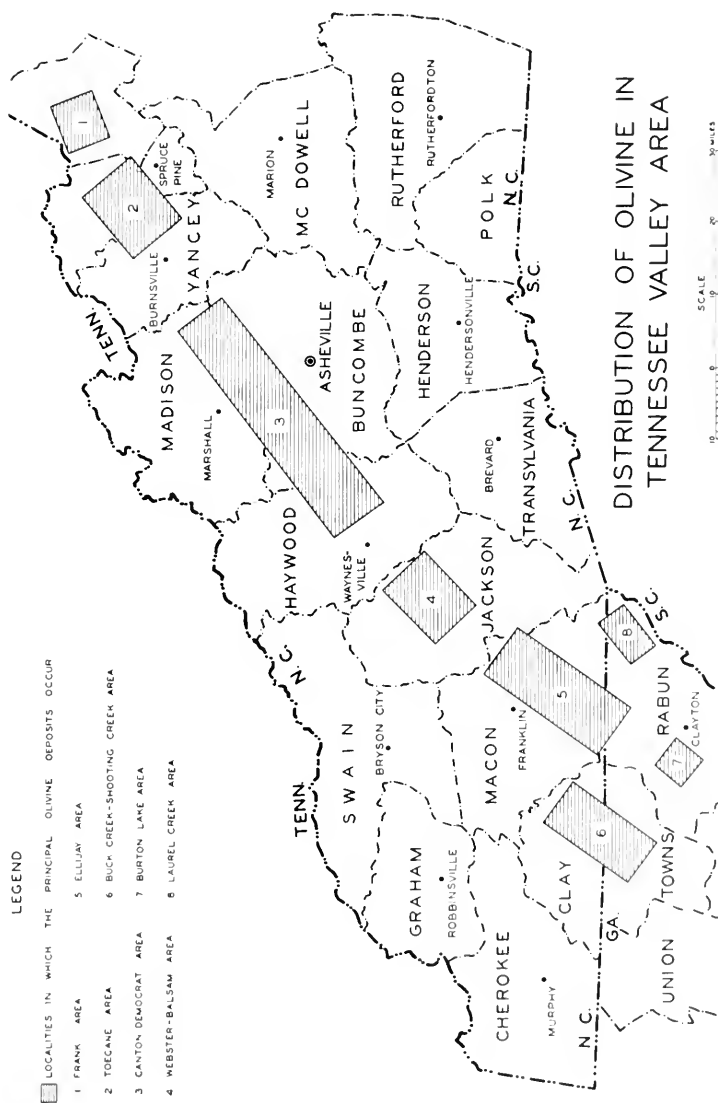
### DESCRIPTION OF AREAS AND DEPOSITS

For convenience of description of deposits and grouping of tonnage estimates, the olivine belt has been divided into eight areas. These areas have been named after prominent geographic points occurring within them. They are listed as follows: (1) Frank, (2) Toecane, (3) Canton-Democrat, (4) Webster-Balsam, (5) Ellijay, (6) Buck Creek-Shooting Creek, all in North Carolina, and (7) Burton Lake, and (8) Laurel Creek, in Georgia (see Plate 8). The extent of any one of the areas is not indicative of the quantity of olivine occurring within its limits. For example, No. 4 (Webster-Balsam), although one of the smallest in areal extent, contains more than twice as much olivine as any other. Also it might be stated that olivine from two or more areas may be drawn to a centrally located point for processing. For example, olivine produced in areas Nos. 3 and 4 (see Plates 8 and 9) could conveniently be processed at any one of several points along the main line of the Southern Railway in the French Broad River valley in the vicinity of Asheville.

### RESERVES OF OLIVINE

Reserve tonnages have been calculated for each of the olivine deposits and totaled for each area. These calcu-

## PLATE 8



lations are based on carefully made geologic maps of each deposit. Most of the deposits were mapped in detail on a scale of one inch equals 500 feet. On these maps the olivine has been divided into two classes—one, relatively unaltered granular olivine, and the other, serpentinized dunite. The areas shown on the maps as “relatively unaltered granular olivine” is composed chiefly of sound, sugary, friable olivine showing little indication of having been altered to other magnesium minerals with inferior refractory and chemical qualities. The olivine included in this classification contains more than 45 per cent MgO and has less than 2 per cent ignition loss. This grade of olivine usually occurs in the central part of the formation.

The area shown on the map as “serpentinized dunite” is composed mainly of faulted and partly serpentinized dunite and saxonite and in some cases includes steatitized material. However, most of it consists of dark olive-green olivine showing some alteration to various secondary magnesium minerals. Included in this classification is material containing at least 40 per cent magnesia suitable for some refractory and most chemical processes. This type of olivine rock usually occurs near the borders of the deposit.

In most cases the topography has been shown on the maps by contours of 50-foot intervals. The elevations were determined with an aneroid barometer. The tonnage calculations for each of the deposits are based only on the olivine and dunite occurring above the local drainage level and are therefore very conservative. This is the material that could be produced from the deposit by a gravity-draining quarry. It is thought that in all deposits more olivine occurs below this level than has been included in the above calculations. Underground mining methods could be used on many of the deposits but this is not necessary because of the existence of



numerous excellent quarry sites having high-grade olivine with little or no overburden. The specific gravity was determined on seventy representative olivine samples taken from the various deposits in the area. The average specific gravity<sup>49</sup> of the olivine was found to be 3.17. From this specific gravity the olivine was calculated to weigh about 200 pounds per cubic foot, which figure was used in making the tonnage estimates.

In making the tonnage estimates, the areal extent of the two grades for each deposit was determined from the geologic map by use of a grid system. The volume determination was made separately for the area between each contour interval. The depth was determined by the local drainage condition at each deposit. The total tonnage for each of the olivine areas is listed in the following table:

TABLE.—OLIVINE RESERVES IN THE TENNESSEE VALLEY REGION.

AREA	Relatively Unaltered Olivine +45% Magnesia -2% Ignition Loss	Serpentinized Dunite 40% to 45% Magnesia +2% Ignition Loss	Total Reserves Per Area
	(tons)	(tons)	(tons)
Frank	2,250,000	10,550,000	12,800,000
Toecane	4,800,000	23,800,000	28,600,000
Canton-Democrat	10,090,000	69,230,000	79,320,000
Webster-Balsam	122,690,000	334,000,000	456,690,000
Ellijay	20,020,000	56,340,000	76,360,000
Buck Creek-Shooting Creek	60,000,000	325,000,000	385,000,000
Burton Lake		25,000,000	25,000,000
Laurel Creek	1,440,000	17,650,000	19,090,000
Other areas (estimated)	12,000,000	85,000,000	97,000,000
Total Reserves	233,290,000	946,570,000	1,179,860,000

<sup>49</sup> Determined by Jolly balance at TVA Minerals Testing Laboratory, Norris, Tennessee.



### FRANK AREA

The Frank area contains approximately 2,250,000 tons of relatively unaltered granular olivine and 10,550,000 tons of serpentinized dunite. This area is in the western part of Avery County, North Carolina, about 45 miles northeast of Asheville. It extends from Plum-tree northward to near Cranberry, a distance of about nine miles, and is about five miles wide. The area lies within rugged mountains; the southern two-thirds is drained by the North Toe River and the remaining third by the Watauga River, both of which are part of the Tennessee River system. U. S. Highway No. 19E traverses the area lengthwise and the E.T. & W.N.C. narrow-gauge railroad serves the northern half of the area.

Two deposits, the Frank and Senia, were mapped and sampled. Several other deposits occur within the area, but they were not mapped or sampled, because they were located at somewhat inaccessible places, and were therefore of little importance for immediate future production of olivine.

### THE FRANK OLIVINE DEPOSIT

The Frank olivine deposit occurs at Frank, N. C., about two miles south of Minneapolis, N. C., on a branch of the E.T. & W.N.C. railroad. U. S. Highway No. 19 passes near the western and northern sides of the deposit, and the North Toe River flows adjacent to and across part of the formation. This deposit is well exposed in two barren hills on the south side of the river (see Plate 10, Fig. A). The larger and westernmost hill rises about 300 feet above river level. The Frank deposit is about 1400 feet long and averages about 400 feet in width.

Slip-fiber anthophyllite asbestos, which occurs in the contact zone of the formation and in many of the interior faults, has been produced intermittently for many

## PLATE 10



FIGURE A.—Barren outcrop of olivine showing asbestos and talc prospects.



FIGURE B.—Olivine outcrop showing thin overburden.

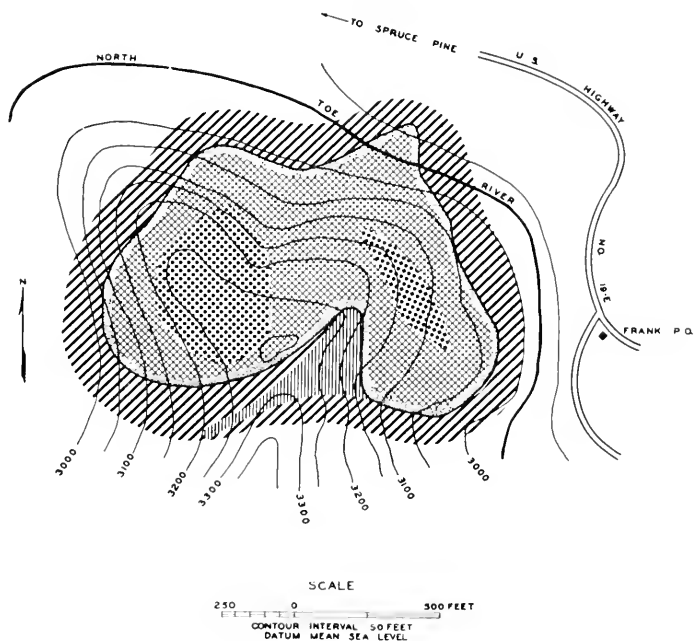


FIGURE C.—Outcrop of coarse-grained olivine showing sharp edges on the boulders which indicate the absence of weathering.

years from this deposit. Vermiculite and a rather pure foliated apple-green talc are associated with the asbestos and have been mined to a limited extent.






A north-south faulted or squeezed zone near the middle divides the deposit into two parts (see Plate 11). The eastern part, which outcrops as a rounded barren

PLATE 11



## FRANK DEPOSIT

## LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLende GNEISS

hill, contains very little overburden except for some residual material between the dunite boulders. This part, composed mostly of coarse-grained granular olivine (see Plate 10, Fig. B), contains irregular areas of closely spaced, small chromite crystals. Hand specimens from the interior of the olivine boulders show little serpentinization to the unaided eye; however, near the faulted or squeezed zone there occur small areas that have been almost completely changed to serpentine, but these are small and closely associated with the slip-fiber asbestos. Several small pegmatites of no economic value outcrop on the northern slope of this hill.

The western part of this formation, the larger of the barren hills, is composed mostly of a fine-grained granular olivine, which consists partly of the interlocking crystalline variety. Here, the olivine ranges from dull green to light brown in color, while that on the opposite hill is of a darker green variety. Few accessory minerals, except large crystals of dark green chlorite in thin veins, occur with the olivine on the western hill. Overburden here, as well as elsewhere on the deposit, is rather thin, usually less than five feet. The western contact is of particular interest because at this point the hornblende schist dips at about 10 degrees to the southeast under the dunite, and there appears to be a rather sharp contact between these two basic materials, a condition which is indicative of a fault contact.

The Frank deposit contains about 2,250,000 tons of relatively unaltered granular olivine and about 9,750,000 tons of serpentinized dunite above river level. The eastern part of the deposit offers good possibilities for quarry sites; and, no doubt, some asbestos, talc, and vermiculite could be obtained from any large-scale operation here.

**PETROGRAPHIC ANALYSIS<sup>50</sup>**

Sample—FRANK B-1. The principal constituents of this specimen are olivine (70 to 80 per cent), the ferruginous enstatite, bronzite (10 to 15 per cent), chlorite (about 5 per cent), chromite (less than 1 per cent), a small amount of antigorite, and a few crystals of talc.

Most of the olivine occurs as large crystals, 1 to 2 mm. in diameter. In the areas where the bronzite is found the olivine crystals are much smaller. The olivine is fairly high in iron, indicated by iron oxide in the antigorite alterations along crystal boundaries.

The chlorite was observed in several fairly large areas and surrounding the chromite crystals.

Sample Frank B-1 has a P.C.E. value<sup>51</sup> of +36.

**THE SENIA DEPOSIT**

The Senia deposit, a mile southwest of Frank Post Office, N. C., outcrops at the mouth of Roaring Creek in a road cut along U. S. Highway No. 19E. Thick hornblende talus conceals much of the formation, but it is thought to be about 800 feet long and 300 feet wide. Olivine exposed in the road cut, about 25 feet above creek level, is a fine-grained granular bluish variety containing chlorite flakes. This deposit is estimated to contain 800,000 tons and is suitable for only a relatively small quarry operation.

Similar deposits occur to the north and east of Frank, N. C., but were not sampled because of their occurrence at points so inaccessible that they are of little value for immediate production. These deposits are likely to enter

<sup>50</sup> Petrographic analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

<sup>51</sup> All P. C. E. values in this report were determined by Gilbert C. Robinson, TVA Minerals Testing Laboratory, Norris, Tennessee. P. C. E. is abbreviation of pyrometric cone equivalent which is used to designate the softening or melting temperatures of ceramic materials. P. C. E. value of +36 means that the sample began to soften at a temperature of 1800 degrees C. The temperature of the olivine cones were brought up to P. C. E. value of 29 at a fast rate and thereafter fired at the standard rate set by the American Ceramic Society.

into production when the demand is sufficient to justify the building of access roads.

#### TOECANE AREA

The Toecane area is characterized by fine-grained dunites and saxonites that have a distinctive yellow color on the weathered surface. This area is estimated to contain 4,800,000 tons of relatively unaltered granular olivine and 23,800,000 tons of serpentinized dunite and saxonite.

The area is about 30 miles northeast of Asheville, N. C. and extends from near the center of Yancey County to a short distance beyond Bakersville in Mitchell County. This area is about 12 miles long and 8 miles wide. The Toe River flows from east to west across the middle of the area and the Clinchfield (C.C. & O.) railroad closely parallels the river. The northern end is served by State Highway No. 19 and the southern by U. S. Highway No. 19E, with many connecting good gravel roads. The whole area lies in mountainous terrain, and the entire drainage is into the Toe River, a part of the Tennessee River system.

#### THE DAY BOOK DEPOSIT

The largest and most outstanding peridotite in the Toecane area is the Day Book deposit occurring about three miles north of Burnsville, Yancey County, N. C., on Mine Fork of Jacks Creek two and one-half miles southwest of the Clinchfield (C.C. & O.) railroad station at Green Mountain.

The Day Book deposit is about 2,000 feet long and 600 feet wide, outcropping as two hills on both sides of Mine Fork Creek (see Plate 12). Each hill rises to about 175 feet above the creek level. The steep sides of the deposit, facing the creek, have practically no overburden. Veins of chromite occur in the dunite at the extreme southwest and northeast ends. This chromite has been prospected at the southern end of the formation by means

of several pits and at the northern end by means of a shaft more than 100 feet deep. Both of these locations are well above the creek level; the chromite content, however, is probably too low to be worked economically.

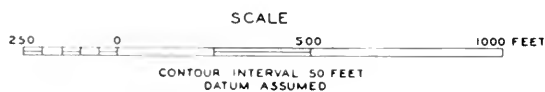
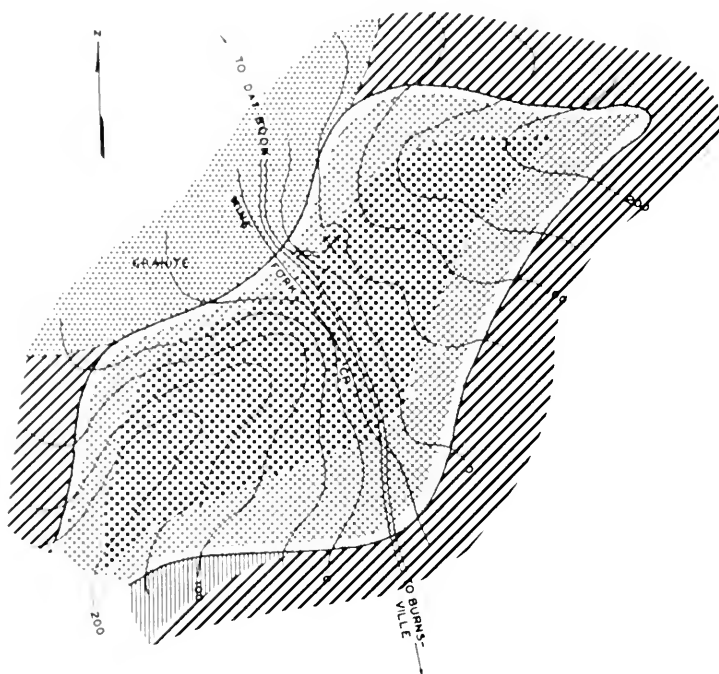
This peridotite consists of partly altered and relatively unaltered dunite and saxonite. Much of the outer portion has been altered by hydrothermal solutions, while the relatively unaltered material occurs as a lens-shaped zone near the center of the formation.

The dunite is composed of fine-grained olivine and small crystals of chromite (see Plate 5, Fig. A). Much of this material is extremely friable, and has a grain size of about 0.2 mm, which is smaller than that of the average olivine. However, near the chromite concentrations, the olivine is quite coarse. Individual grains, ranging from 3 to 4 mm in diameter, were noticed near the chromite pits south of Mine Fork Creek. The degree of serpentinization in the dunite is comparatively small.

The saxonite is composed essentially of fine-grained friable olivine, many bronzite crystals, and small amounts of chromite (see Plate 5, Fig. B). This rock occurs surrounding, and as fault blocks within, the dunite. In most cases the bronzite, often comprising 15 per cent of the rock, has been partly or completely altered to talc.

The second largest olivine quarry in North Carolina is located above the road in the west central part of the formation (see Plate 13, Fig. A). This quarry has been an intermittent producer of olivine for about five years. The olivine produced is divided into two types. Grade 1 consists of fine-grained friable, fresh material containing practically no accessory minerals except chromite. This grade is produced almost entirely from the dunite. Grade 2 is a fine-grained, friable olivine which contains talc in noticeable quantities. Most of the talc is an alteration product of the bronzite. Near the faults and larger

## PLATE 12



## DAY BOOK DEPOSIT

## LEGEND






-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLende GNEISS



PLATE 13



FIGURE A.—Olivine quarry after blast. Note vertical drill holes in quarry face.



FIGURE B.—Small olivine quarry in large residual boulders of dunite.

joints in the Day Book deposit the olivine shows signs of chloritization. This material is discarded when encountered in quarrying. The Day Book deposit has excellent topography for two large quarries. This deposit is estimated to contain 3,180,000 tons of relatively unaltered granular olivine and 6,710,000 tons of serpentinized dunite above the level of Mine Fork Creek.

#### CHEMICAL ANALYSIS

##### AVERAGE OF FIVE COMMERCIAL SHIPMENTS<sup>52</sup>

MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	Mk.	Ign. Loss	Total
48.77	40.93	7.60	1.32	0.29	0.13	1.09	100.13

##### FINE-GRAINED DUNITE RELATIVELY UNALTERED OLIVINE

Samples <sup>53</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Ti, Cr, Al, (Oxides)	CaO	Ign. Loss
Day Book A-1	49.31	40.86	7.66	2.18	0.00	0.63

##### FINE-GRAINED SAXONITE PARTLY ALTERED

Samples <sup>53</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Ti, Cr, Al, (Oxides)	CaO	Ign. Loss
Day Book A-2	45.92	42.40	8.62	1.06	0.00	1.23

#### PETROGRAPHIC ANALYSIS<sup>54</sup>

Sample<sup>55</sup>—DAY BOOK A-1. (Fine-grained dunite.) The principal constituent of this rock is quite fresh olivine constituting about 95 per cent of the whole. The crystals vary in size between 0.1 and 1.0 mm., averaging about 0.3 mm.

Two thin stringers of talc were observed cutting through the hand specimen. No estimate

<sup>52</sup> Analysis by John Boyd of the United Feldspar and Mineral Company, Spruce Pine, North Carolina.

<sup>53</sup> Chemical analysis made by TVA Minerals Testing Laboratory at Norris. Note that samples Day Book A-1 and A-2 are similar to specimens shown on Plate 5.

<sup>54</sup> Petrographic analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

<sup>55</sup> Note that samples Day Book A-1 and A-2 represent material as shown on Plate 5.

can be made of the amount present; however, it is evidently small.

The rock also contains about 1 to 2 per cent of chromite crystals scattered throughout the rock and a small amount of chlorite (less than 1 per cent).

Sample<sup>56</sup>—DAY BOOK A-2. (Altered fine-grained saxonite.) The principal constituent of this rock is a quite fresh, low-iron olivine making up about 60 to 70 per cent of the rock. The olivine shows a small amount of alteration to antigorite along crystal boundaries. The olivine crystals are rather small, varying in size between 0.05 and 0.3 mm.

In addition to the olivine, the rock contains about 10 per cent each of long prismatic crystals of tremolite and nodular aggregates of talc. The tremolite crystals were found cutting through the olivine and also in the talc areas. Much of the talc contains inclusions of brown substances too fine to identify. Probably these inclusions are from the original rock from which the talc was formed. A few small remnants of a pyroxene mineral, probably bronzite or hypersthene, were observed.

Scattered crystals of chromite (1 to 2 per cent) were observed throughout the rock. Surrounding the chromite are bladed crystals of chlorite. Chlorite was observed in other areas. The total amount of chlorite is estimated at about 5 per cent.

#### P. C. E. VALUE

Sample Day Book A-1 has a P. C. E. Value of +36.

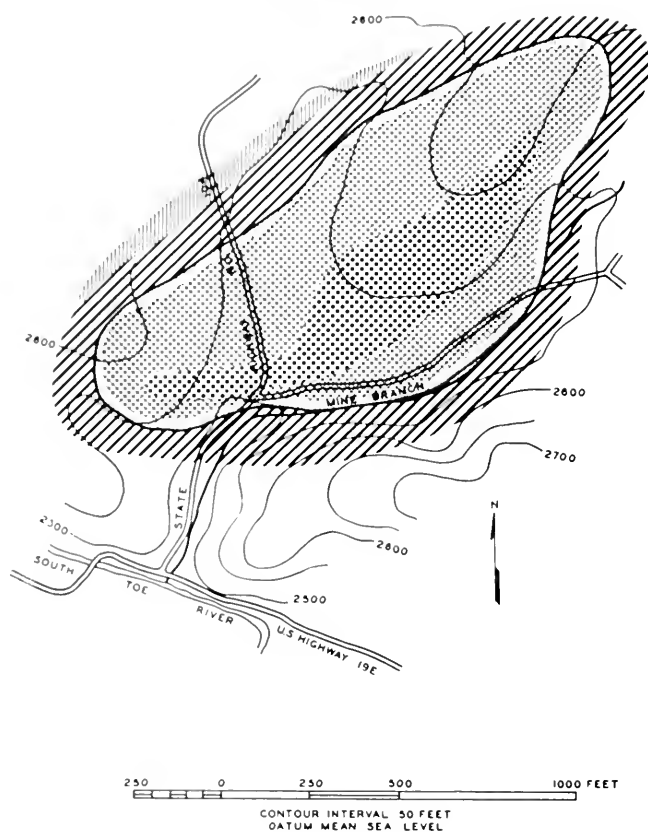
#### THE NEWDALE OLIVINE DEPOSIT

The Newdale olivine deposit is located one and three-fourths miles east of Micaville, Yancey County, North Carolina and one-fourth of a mile up Mine Branch, a tributary of South Toe River. The Clinchfield (C.C. & O.) railroad at Boonford is within one and one-half miles of the deposit.

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<sup>56</sup> Note that samples Day Book A-1 and A-2 represent material as shown on Plate 5.

PLATE 14



## NEWDALE DEPOSIT

## LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLLENDE GNEISS

The dunite outcrops on two low hills, about 125 feet high, on each side of the road (see Plate 14). The formation is approximately 1800 feet long and 500 feet wide, most of which is barren or covered with small scrub growth.

The olivine in this deposit is similar to that at Day Book in that it is extremely fine grained, pale green and yellow in color. However, scattered olivine crystals occur as large as  $1\frac{1}{2}$  inches in diameter at several places throughout the formation. Near the middle portion of the formation large chromite octahedron crystals are rather conspicuous, but these, upon close examination, are found to be thinly spaced in the formation. No saxonite was observed.

Along the southeastern part of this deposit there occurs a barren bluff in the dunite. Here the formation consists of a gray-green, inter-locking, crystalline, tough-type olivine. The grain size is larger than is usually found in this variety.

One of the outstanding structural features of this deposit is the occurrence of smooth and straight vertical joints extending as much as 75 feet through the dunite. Expansion joints parallel to the surface (see Plate 15, Fig. A) are important structural features found in all the fine-grained dunites. The southwestern nose of the formation contains a fringe about 50 feet wide of soapstone and interlocking anthophyllite asbestos. Most all the olivine occurring along the southern contact of the formation, is highly serpentinized and contains small areas of soapstone and anthophyllite asbestos. This deposit has suitable topography for two or more quarry sites in granular and relatively fresh olivine. It is estimated that the Newdale deposit contains 1,560,000 tons of relatively unaltered granular olivine and 5,090,000 tons of serpentinized dunite above South Toe River.

## PLATE 15



FIGURE A.—Dunite outcrop showing thin overburden and expansion joints paralleling the surface.



FIGURE B.—Vermiculite prospect exposing fault zone in dunite. Note the broken condition of the olivine, vertical fault face at left of picture, and slickensided talc (white) on boulders.

**CHEMICAL ANALYSIS**COMMERCIAL SHIPMENTS OF OLIVINE<sup>57</sup>

MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	Ign. Loss	Total
47.81	41.06	7.27	1.53	.24	2.43	100.34

Sample Newdale B-1 has a P.C.E. value of +36.

**THE BAKERSVILLE OLIVINE DEPOSIT**

The smallest peridotite sampled in the Toecane area is the Bakersville olivine deposit located on White Oak Creek, one mile southeast of Bakersville, Mitchell County, N. C., and two and one-half miles east of the Clinchfield (C.C. & O.) railroad station at Toecane. This deposit outcrops on the nose of a low hill south of White Oak Creek. While all of the dunite is not visible because of overburden, it is thought to be about 300 feet long and 60 feet wide. The highest outcrop is only 30 feet above White Oak Creek. The olivine is medium-grain, granular, and semi-friable with a high uniform chromite content. The most unique feature about this deposit is the presence of chrysotile asbestos which occurs as seams up to 6 inches thick and as individual fibers and clusters of fibers penetrating individual olivine grains. This deposit is estimated to contain 50,000 tons of relatively unaltered granular olivine above White Oak Creek.

The deposits described above are by no means all the olivine deposits occurring in the Toecane area. However, they do represent the most important. Other deposits, such as the one near Loafers Glory, were not sampled because they had undergone extreme hydrothermal alteration, or because their location was inaccessible for commercial production.

<sup>57</sup> Analysis made by John Boyd, United Feldspar & Mineral Company, Spruce Pine, North Carolina

### CANTON-DEMOCRAT AREA

The Canton-Democrat area is estimated to contain 10,090,000 tons of relatively unaltered granular olivine and 69,230,000 tons of serpentinized dunite.

This area extends as a belt about 10 miles wide, from Junaluska in Haywood County, to Barnardsville in Buncombe County, a distance of about 30 miles. The center of this area is about 8 miles west of Asheville, N. C. In contrast to the usual rugged topography of western North Carolina, this area consists of large rolling hills, and wide-bottomed valleys. Drainage is directly or indirectly into the French Broad River which flows across the center of the area.

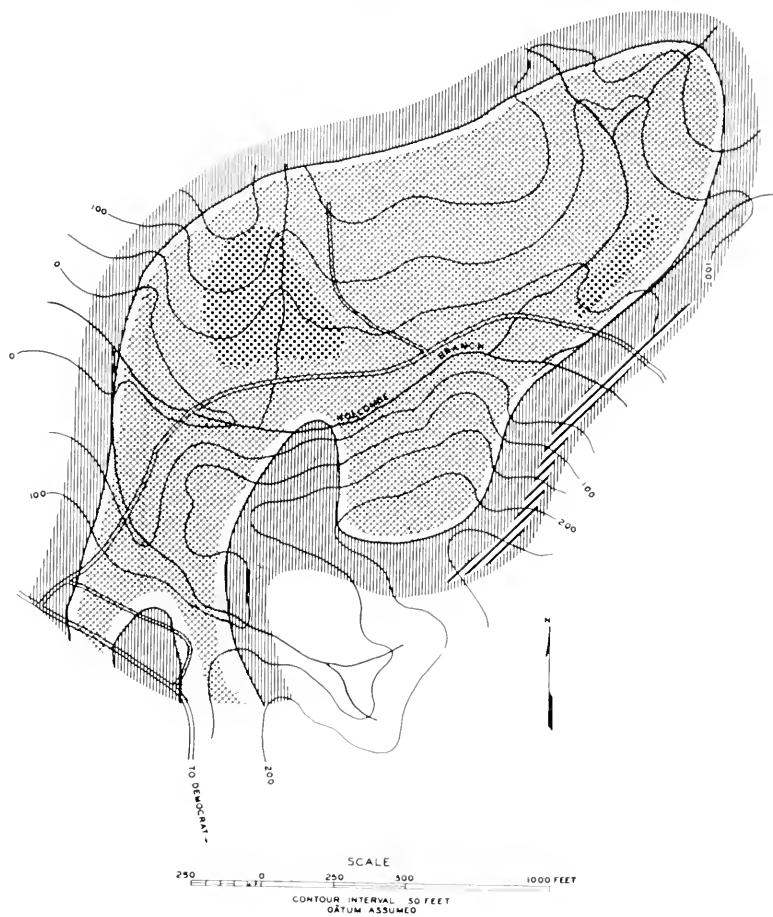
The Asheville-Knoxville branch of the Southern Railway crosses the center of the area; and the Asheville-Murphy branch crosses the southwestern end. U. S. Highways 70 and 25, and 19 and 23 supplemented by State Highways 63, 197, and 209, are important routes for local commerce. Asheville, N. C., a few miles south of the area, is the largest and the most important city in western North Carolina, and because of its central location should become an important olivine-processing center.

### THE HOLCOMBE BRANCH OLIVINE DEPOSIT

The Holcombe Branch olivine deposit is located one and one-half miles north of Democrat and 15 miles north of Asheville on both sides of Holcombe Branch in Madison County, North Carolina. The deposit is very irregular in outline, the maximum length being about 3,000 feet and the maximum width approximately 1,500 feet. The formation is somewhat broken up by faults and it contains several schist inclusions. The part of the formation lying south of Holcombe Branch has been the most disturbed and contains a higher percentage of soapstone than does the northern half. Much of the northern half of the formation, especially the area near a small branch








PLATE 16



HOLCOMBE BRANCH DEPOSIT

LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLende GNEISS

in the western part, is granular, and light yellow in color but apparently relatively sound (see Plate 16). Chromite crystals are rather conspicuous in the material and secondary minerals such as talc and chlorite are mostly confined to joints. The surface part of boulders and outcrops are exceptionally friable. The parts of the Holcombe Branch deposit that are fine-grained and yellow in color are similar in appearance to the Day Book and Newdale material. This deposit contains about 3,530,000 tons of relatively unaltered granular olivine and 17,500,000 tons of serpentinized dunite above Holcombe Branch level. The granular material can be quarried or mined below Holcombe Branch level so that the economically recoverable olivine is about twice the amount given above. During early 1941 a new quarry and crushing plant was opened on the Holcombe Branch deposit which makes this the third active producer of olivine in the TVA region.

#### PETROGRAPHIC ANALYSIS<sup>58</sup>

Sample—HOLCOMBE BRANCH DUNITE. The dunite (the Holcombe Branch area) is composed of a fine-grained laminated rock, varying in color from light yellowish green to dark green and almost black. With the exception of occasional grains and crystals of chromite, no constituent but olivine is visible.

Most of the sections show a very fine-grained rock, the grains averaging 0.1 to 0.2 mm. in diameter, but with crossed nicols these are found to polarize together over considerable area, showing the grains to have been originally 0.6 to 1 mm. in diameter. . . . In all cases the granules are separated from each other by a thin development of yellowish or greenish serpentine.

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<sup>58</sup> Pratt and Lewis, *op. cit.*, p. 108.

Sample Holcombe Branch A-2 has a P.C.E. value of +36.

#### THE DEMOCRAT DEPOSIT

The Democrat deposit occurs in Buncombe County one and one-half miles southwest of the Holcombe Branch deposit. This deposit is one-half mile west of Democrat and extends from Ivy Creek southwestward for one and one-half miles. The formation is approximately 600 feet wide at its northern end and tapers gradually to a narrow belt at the southwestern end.

Most of the formation is covered with residual overburden and in many places it is as much as 20 feet thick. However, adjacent to Ivy Creek the overburden is thin where the grade is fairly steep. The entire formation is serpentized to such an extent that it is noticeable in all the outcrops. The dark serpentized streaks obscure much of the chromite occurring as disseminated crystals throughout the olivine. The formation is cut by several large pegmatites, two of which are intermittently worked for high-grade feldspar (see Plate 17, Fig. A). Nickel silicate minerals occurring in cracks, joints, and as inclusions are visible wherever there is a good exposure of the formation. Many years ago the formation was prospected for nickel minerals comparable to those occurring at Webster, N. C.

This deposit is not well suited for the production of olivine alone, but it is worthy of attention because of the occurrence of nickel silicate minerals and disseminated crystals of chromite in the partly serpentized dunite. This formation probably contains as much chromite as any in the entire olivine belt. It is estimated that the Democrat deposit contains 25,000,000 tons of serpentized dunite and 2,000,000 tons of relatively unaltered granular olivine above Ivy Creek level.

## PLATE 17



FIGURE A. Large pegmatite in dunite. Note small pegmatite in top contact, sheared talc above, and dark-colored serpentinitized dunite in top right corner.



FIGURE B.—Dunite showing joint systems.

**CHEMICAL ANALYSIS<sup>59</sup>****HIGHLY SERPENTINIZED DUNITE**

Sample <sup>60</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Ti, Cr, Al, (Oxides)	CaO	Ign. Loss
Democrat A-1	45.39	40.18	8.94	1.48	0.00	3.76

**PETROGRAPHIC ANALYSIS<sup>61</sup>**

Sample—DEMOCRAT, A-1. The rock appears to have been nearly all olivine before alteration, which is quite extensive at crystal boundaries. The olivine crystals vary in size between 0.1 and 1.2 mm. with an average diameter of about 0.4 mm.

The alteration product of the olivine is chrysotile serpentine with a small amount of antigorite. The chrysotile fibers are very short with a maximum observed length of 0.1 mm. The serpentine appears to make up 10 to 15 per cent of the rock.

Occuring with the olivine crystals are small (maximum of 0.1 mm.) crystals of a pyroxene which appears to be diopside. The pyroxene constitutes about 2 to 3 per cent of the rock.

A small quantity (less than 1 per cent) of chromite and a negligible quantity of chlorite were observed.

**THE JUNO DEPOSIT**

The Juno deposit occurs one and three-fourths mile southeast of Leicester, Buncombe County, N. C., and about five miles northwest of Asheville. This is a serpentine deposit and is described here because it is probably the only occurrence of its kind in the entire olivine belt. The serpentine body is about 800 feet long and approximately 60 feet wide with most of this area containing little or no overburden. The serpentine is dark green in color and highly fractured. A few fragments of the

<sup>59</sup> Chemical analysis made by TVA Minerals Testing Laboratory, Norris, Tenn.

<sup>60</sup> Sample Democrat A-1 similar to material shown in Plate 7, Fig. C.

<sup>61</sup> Petrographic analysis made by W. Wurth Krieger, Department of Ceramic Engineering, University of North Carolina, Raleigh, N. C.

original olivine are noticeable in some of the freshly broken pieces of the serpentine; the original chromite crystals, however, have been unaffected and in some places are rather conspicuous. Cracks and seams in the material are filled with visible secondary magnetite. Tale and chlorite occur along many of the joints in the serpentine; also associated with the joints are impure chalcedony and possibly remnants of nickel silicate minerals.

Outcrops of the Juno deposit are light gray in color and the weathered material is porous, with a specific gravity about one-third less than that of the fresh material. The weathering extends to a depth of about 10 feet. The Juno deposit contains about 95,000 tons of "quarrrable" serpentine.

#### PETROGRAPHIC ANALYSIS<sup>62</sup>

Sample—JUNO, A-2. The major constituent of this rock is antigorite serpentine. Of the original rock only pseudomorphs of a compact, moderate relief, low birefringent mineral remain. The properties are very similar to those of the antigorite with the exception of a slightly higher birefringence. Some of these remnants are stained by iron oxide. It might be that these are the mineral bastite formed from olivine.

The black banding is the result of high concentration of small crystals of magnetite in those areas. A few crystals of chromite were observed.

#### P. C. E. VALUE

Sample Juno A-1 has a P.C.E. value of 23 to 26.

One-fourth of a mile west of this deposit, the state highway crosses a dunite body which is about 800 or 900 feet wide. The material in this deposit is extremely serpentinized and weathered, so it is of doubtful value as an olivine deposit. Many other small and similar deposits occur in this same vicinity.

<sup>62</sup> Petrographic analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, N. C.

**NEWFOUND GAP DEPOSIT**

The Newfound Gap dunite occurs in Newfound Gap on the Haywood-Buncombe County line about 15 miles west of Asheville. This occurrence is five miles northeast of the railroad station at Canton, N. C.

The Newfound Gap deposit is 1000 feet long and 250 feet wide at its widest point (see Plate 18). The dunite occurs well above the local drainage system and it rises abruptly in a steep hill south of the state highway. The olivine in this formation is of a light green, granular, friable type with crystals and large blebs of chromite rather conspicuous throughout the mass. The olivine on outcrops is relatively sound and the hand specimen shows little alteration to serpentine. However, part of this formation, especially near the southern part, consists of brownish interlocking crystalline olivine probably of inferior refractory properties. Near the northeastern end where the highway crosses the formation the dunite is of the bluish tough variety containing chlorite.

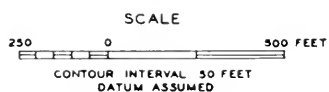
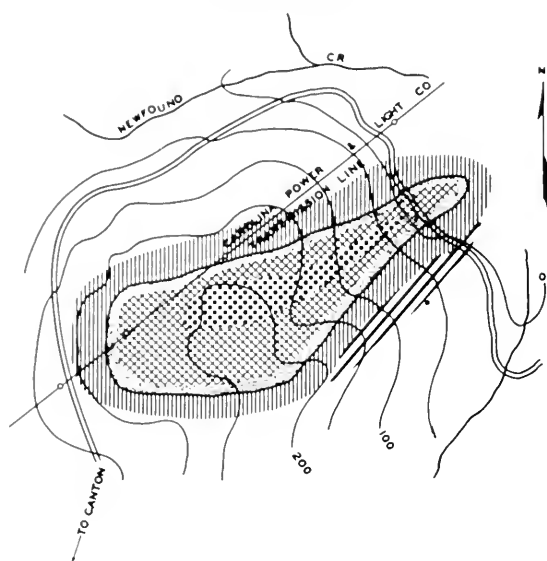
The topography of this deposit is well suited for a quarry and its location is within trucking distance of Canton or Alexander, N. C. It is estimated that this deposit contains 1,310,000 tons of relatively unaltered granular olivine and 6,640,000 tons of serpentized dunite.

Sample Newfound Gap A-2 has a P.C.E. value of +36.

**THE HOMINY GROVE OLIVINE DEPOSIT**

The Hominy Grove olivine formation occurs two and one-fourth miles northeast of the railroad station at Canton, Haywood County, N. C. The eastern end of the deposit outcrops at the back of Hominy Grove Church. This dunite is approximately 2,000 feet long and 200 feet wide with the long axis trending east and west. Most of this formation is covered with thick overburden, part of which was observed to consist of gravel and clay

## PLATE 18



## NEWFOUND GAP DEPOSIT

## LEGEND

	RELATIVELY UNALTERED GRANULAR OLIVINE
	SERPENTINIZED DUNITE
	TALCY VERMICULITE FRINGE ZONE
	BIOTITE SCHIST
	HORNBLende GNEISS



banks, probably terrace deposits from the Pigeon River. The eastern quarter of the deposit is best exposed and here the dunite, consisting of dark gray and green compact interlocking grains of olivine, outcrops in erosion gulches. This material in hand specimen shows indication of slight serpentinization. A small area adjacent to the church was also observed to consist almost entirely of a fresh coarse-grained granular olivine similar to that occurring at Newfound Gap. This deposit is thought to contain about 20,000,000 tons of serpentinized dunite and 1,000,000 tons of relatively sound olivine.

#### **WEBSTER-BALSAM AREA**

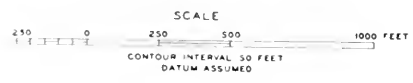
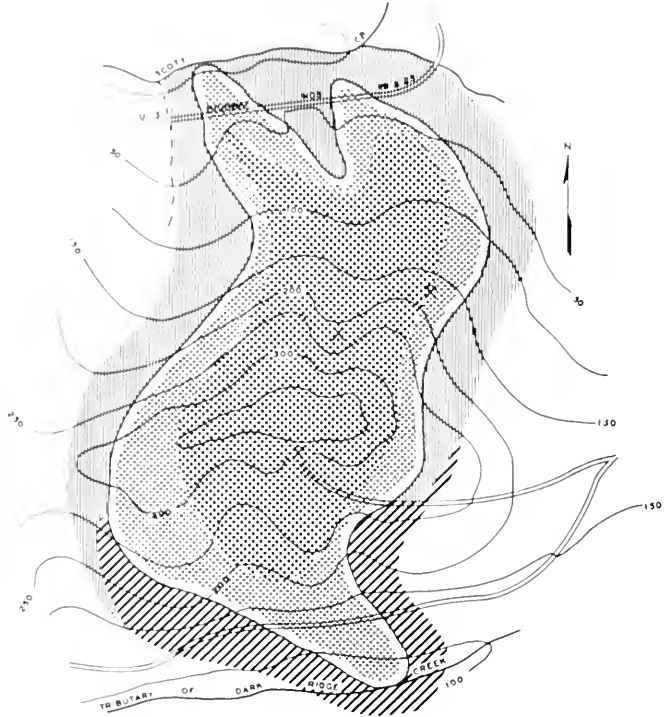
The Webster-Balsam area is estimated to contain 122,690,000 tons of relatively unaltered granular olivine and 334,000,000 tons of serpentinized dunite. This area contains the largest reserve of olivine of all the areas.

The Webster-Balsam area is about 35 miles southwest of Asheville and extends from near the center of Jackson County northeastward to the Jackson-Haywood county line at Balsam Gap, with a length of about 15 miles and a width of approximately 8 miles. The southwestern end of the area is in the Tuckasegee Valley where low, rounded, hilly topography predominates and the eastern end is in the rugged Balsam Mountains. The Asheville-Murphy branch of the Southern Railway passes through the area from end to end, and the Tuckasegee and Southeastern branch line passes across the southwestern part of the area. The Webster-Balsam area is well served by U. S. Highways Nos. 19 and 23 and numerous secondary highways.

#### **THE BALSAM GAP OLIVINE DEPOSIT**

The Balsam Gap olivine deposit is in the eastern part of Jackson County, one-half mile southwest of the Southern Railway station at Balsam. U. S. Highways Nos. 19 and 23 pass over the northern end of this deposit.

PLATE 19



BALSAM GAP DEPOSIT

LEGEND






-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLLENDE GNEISS

PLATE 20



FIGURE A.—Olivine deposit showing usual conical shape.

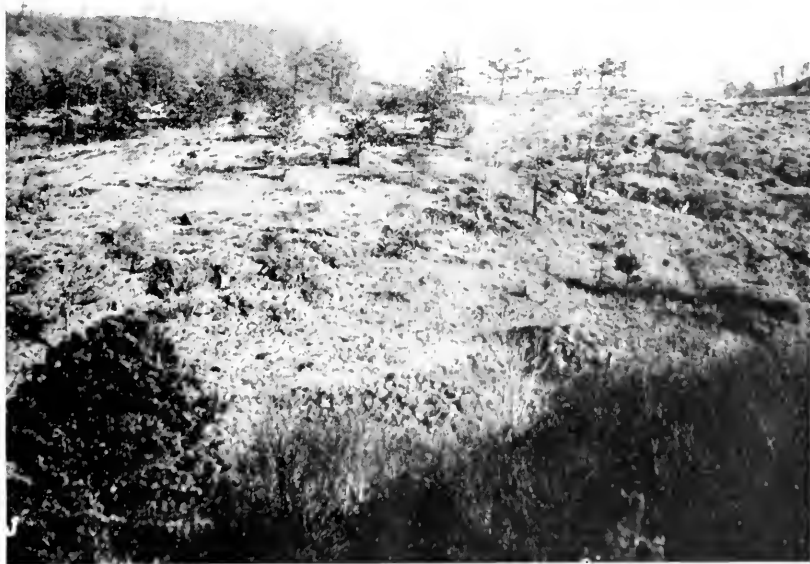


FIGURE B.—Olivine outcrop showing stunted vegetation common to many deposits.

This deposit is about 2,000 feet long and approximately 800 feet wide at the widest point, with the long axis trending north and south (see Plate 19). The center of the deposit lies 350 feet above the nearby drainage system. This central portion, about 500 feet in diameter, rises as an almost sheer bluff (see Plate 20, Fig. A) from which huge boulders of olivine have rolled a considerable distance down the slope. These boulders are rather sound, and from a practical quarrying standpoint, are not classified as overburden. The overburden consists of residual boulder fragments and red soil derived from the olivine.

The Balsam Gap deposit is composed of relatively sound dunite and saxonite. Most of the saxonite and altered materials are segregated near interior faults and the borders of the formation. Much of the Balsam Gap deposit is composed of light green, coarse-grained, friable dunite containing few accessory minerals with little visible serpentinization in the hand specimen (see Plate 4, Fig. A). About one-fourth of the deposit is made up of coarse-grained and light green saxonite containing spots of talc (see Plate 4, Fig. B). Upon close examination these talc blebs are found to be an alteration product of the bronzite crystals which are rather numerous in the saxonite. These bronzite crystals average about one-fourth inch in diameter but some crystals were observed with diameters of over one inch. At many points, especially near the borders of the coarse-textured dunite, there are small zones, often up to three feet wide and several times this in length, of magmatic segregated chromite intermixed with the olivine. An analysis of this material made at the Minerals Testing Laboratory shows that it contains 3.60 per cent of chromium oxide.

The Balsam Gap deposit is broken into large blocks by numerous faults and joints. Partly because of its occurrence high above the local drainage level, weather-

ing and clay have penetrated downward along joints and faults deep into the deposit.

The Balsam Gap deposit contains about 17,330,000 tons of relatively unaltered granular olivine and 32,860,000 tons of serpentized dunite above Scott Creek level.

The first commercial production of olivine in the United States came from a quarry in the Balsam Gap deposit (see Plate 21, Fig. A). This quarry has been in operation since 1933 and has produced more than half of the olivine marketed from North Carolina. Another quarry, 750 feet to the northeast, has been worked intermittently. The topographic features of this deposit are such that large quarries on several sides of the deposit can be operated simultaneously.

#### CHEMICAL ANALYSIS

##### ANALYSIS OF COMMERCIAL SHIPMENTS—BALSAM GAP OLIVINE<sup>63</sup>

Samples	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO
N.....	48.45	42.26	8.82	0.10
S.....	47.99	41.60	8.60	0.00

##### RELATIVELY UNALTERED OLIVINE

Samples <sup>64</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Ti, Al, Cr, (Oxides)	CaO	Ign. Loss
Balsam Gap A-1.....	50.12	39.90	8.94	1.86	0.00	0.49

##### SLIGHTLY ALTERED SAXONITE

Samples <sup>64</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Ti, Al, Cr, (Oxides)	CaO	Ign. Loss
Balsam Gap A-2.....	47.00	41.34	8.78	1.22	0.00	1.57

<sup>63</sup> Chemical analysis by John Boyd, United Feldspar and Minerals Company, Spruce Pine, North Carolina.

<sup>64</sup> Sample A-1 represents best grade and Sample A-2 second grade as commercially shipped. Chemical analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

PLATE 21



FIGURE A.—Olivine Quarry.



FIGURE B.—Screening out fines in olivine quarry after blast.

## COARSE-GRAINED DUNITE RELATIVELY UNALTERED OLIVINE

Balsam Gap Samples <sup>65</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
B-2	50.14	39.96	10.70	0.74	0.00	0.33
C-1	49.31	40.90	9.58	0.50	0.00	0.92

## COARSE-GRAINED SAXONITE PARTLY ALTERED

Balsam Gap Samples <sup>65</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
B-3	46.72	43.18	9.10	1.30	0.00	0.69

## CHROMITE IN DUNITE RELATIVELY UNALTERED OLIVINE

Balsam Gap Samples <sup>66</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
B-1	47.80	38.62	9.74	5.90	0.28	0.31

## P. C. E. VALUE

Sample Balsam Gap A-1 has a P.C.E. value of +36 to 38.

Sample Balsam Gap A-2 has a P.C.E. value of +36.

PETROGRAPHIC ANALYSIS<sup>67</sup>

Sample—BALSAM GAP A-1. The rock consists essentially of light green olivine, showing very little alteration. The olivine crystals have a minimum size of 0.1 mm., a maximum of 5 mm., and an average of about 3 mm. The crystals show less than normal shattering. The rock contains a very small

<sup>65</sup> Note that Samples Balsam Gap B-2 and C-1 are material similar to that in specimen shown in Plate 4, Fig. A, Sample B-3 is similar to specimen shown in Plate 4, Fig. B, and Sample B-1 is material similar to specimen shown in Plate 1. Chemical analysis made at TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>66</sup> Note that Samples Balsam Gap B-2 and C-1 are material similar to that in specimen shown in Plate 4, Fig. A, Sample B-3 is similar to specimen shown in Plate 4, Fig. B, and Sample B-1 is material similar to specimen shown in Plate 1. Chemical analysis made at TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>67</sup> Petrographic analysis made by W. Wirth Krieger, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

amount (less than 1 per cent) of chromite and magnetite.

The vein that is observed in the hand specimen was found to be a fracture zone or band. Most of the fractures are filled with very thin seams of chrysotile and a few skeletons of magnetite. A few small crystals of chlorite were also observed in this zone. The vein makes up less than one per cent of the hand specimen.

Sample—BALSAM GAP A-2. The rock is quite highly altered. The principal minerals are olivine (about 60 per cent), talc (20 to 30 per cent), antigorite (about 5 per cent), and a small amount of chlorite, chromite, and magnetite.

The olivine grain sizes vary from 0.05 to 3 mm. in diameter. About half of the rock is quite fresh, with little fracturing. The remaining half is quite shattered and shows alteration to antigorite. Of many crystals, only remnants remain from the alteration. A few of the grains show alteration across the grains and along the borders to ferro-mineral similar to bowlingite. Magnetite is found in the fissures with the antigorite.

The talc appears to be an alteration product of a pyroxene of which only ghost cleavages remain. Several sections were found showing inclusions and typical bronzite schiller structure. The talc contains magnetite.

A few small crystals of chromite surrounded by chlorite were found. Some of the chlorite is partially altered to antigorite.

#### THE MIDDLETON DEPOSIT

The Middleton dunite occurs approximately 1,200 feet southwest of Balsam Gap deposit. The dunite is about 180 feet wide and 400 feet long, which makes it one of the smallest in the area. The main outcrop is on the crest of a steep-sided ridge, about 300 feet above a tributary of Jones Creek. Most of the western half of the deposit is altered to soapstone.



Near the eastern extremity of this formation a small pit blasted into the fresh dunite has exposed a medium-grained, light green, friable olivine similar to that at the Balsam Gap deposit. Accessory minerals are almost entirely lacking in the exposed part of the deposit, except talc occurring in narrow veins. This deposit contains about 500,000 tons of relatively unaltered granular olivine and 100,000 tons of serpentinized dunite.

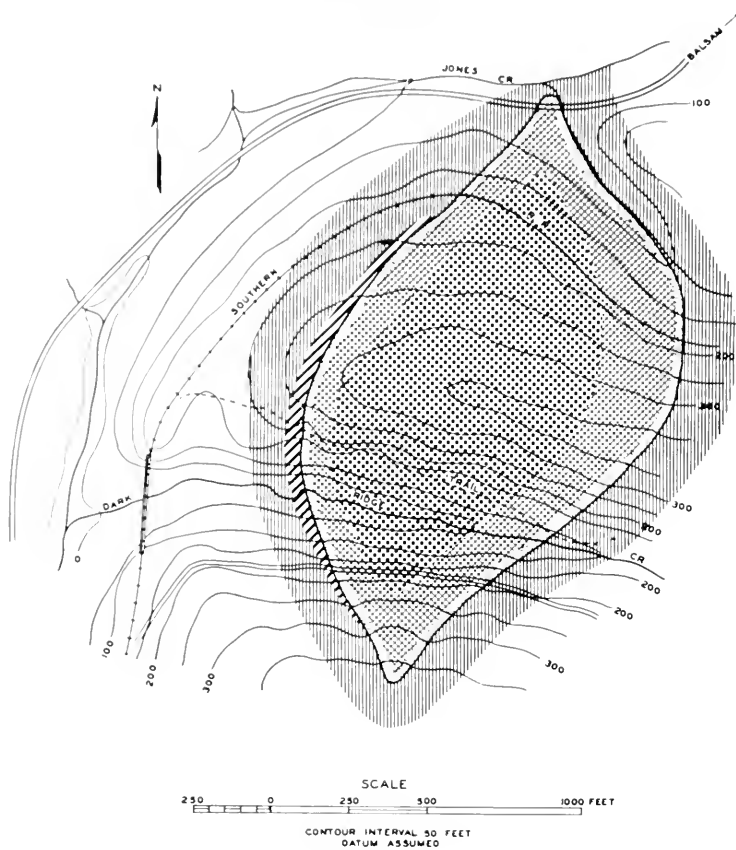
#### **DARK RIDGE DEPOSIT**

One of the more important peridotite formations in the Webster-Balsam area is the Dark Ridge olivine deposit. It is located along the Southern Railway, one and one-fourth miles southwest of Balsam station, and 400 feet east of Dark Ridge trestle. The deposit occurs as a north-south trending, lemon-shaped formation about 2,000 feet long, and has a maximum width of 900 feet.

The main part of the deposit forms an east-west spur (see Plate 22) which rises abruptly from the nearly valley floor to a height of about 400 feet. Dark Ridge Creek crosses the southern part, and Jones Creek bounds the northern end of the formation. The best exposures are on the north side of Dark Ridge Creek where a bluff of olivine rises steeply to a height 400 feet above creek level. Other good exposures occur along the Southern Railway cuts in the northern part of the deposit.

This peridotite is composed of unusually coarse-grained dunite and saxonite. Two-thirds of the deposit consists of relatively unaltered dunite, forming a large lens-shaped core surrounded by saxonite. The dunite consists of relatively sound, dark green, granular, friable olivine. Giant shattered olivine crystals, as large as six inches in diameter occur throughout the core. To the unaided eye the material shows no signs of serpentinization. Small crystals of chromite are visible throughout the dunite and at many places seams of massive chromite outcrop.

## PLATE 22



## DARK RIDGE DEPOSIT

## LEGEND






-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLende GNEISS

PLATE 23



FIGURE A.—Refractory grades of block olivine.



FIGURE B. Crude forsterite olivine blocks ready for use in furnace walls

The saxonite occurs chiefly in the border zone of the formation or as small fault blocks within the dunite. The saxonite is partly altered to serpentine and steatite, especially near the contacts. However, most of it is relatively sound and is composed principally of coarse-grained, granular, dark green olivine. The bronzite crystals, often altered to talc, averages about one-fourth inch in diameter, and makes up 10 per cent of the rock.

The Dark Ridge deposit is one of the most outstanding olivine formations in the entire olivine belt. It is not only one of the largest, but also one of the least altered. Most of the alteration has been of an auto-metamorphism character as no indications of pegmatitic intrusions are seen in the formation. The proportion of sound olivine is high in comparison to that of altered material in other deposits. This deposit contains 16,550,000 tons of relatively unaltered granular olivine and 24,500,000 tons of partly serpentized dunite and saxonite above Dark Ridge Creek level.

The topography of this deposit is ideal for a large quarry so located that the olivine can be loaded directly into railway cars.

#### CHEMICAL ANALYSIS<sup>68</sup>

##### COARSE-GRAINED DUNITE RELATIVELY UNALTERED OLIVINE

Dark Ridge Samples	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
A-1	49.69	41.00	9.74	0.38	0.00	0.61

##### STEATITIZED AND WEATHERED DUNITE

Dark Ridge Samples	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
A-2	44.08	43.60	9.90	1.76	1.23	1.51

<sup>68</sup> Chemical analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

**P. C. E. VALUE**

Sample Dark Ridge A-1 has a P.C.E. value of 36 to 38.

Sample Dark Ridge C-6 has a P.C.E. value of 36 to 38.

**PETROGRAPHIC ANALYSIS<sup>69</sup>**

Sample—DARK RIDGE A-1. The olivine, which is the principal constituent of the rock, is quite fresh, with the majority of the crystals showing little or no fracturing; however, a few of the crystals are badly shattered. A small amount of serpentinization has taken place around the borders of some of the crystals. The olivine crystals vary in size from about 0.2 mm. to about 2 mm. in diameter with an average of about 1 mm.

A few large (about 5 mm.) crystals of bronzite were found in the rock. The amount would not exceed a very few per cent.

The chromite in this sample is for the most part fine-grained (about 0.05 mm. in diameter) with a few large crystals (3 to 4 mm. in diameter). In all but one case the chromite is surrounded by olivine crystals. The one exception had a few small plates of chlorite around the chromite. The chromite comprises about 2 to 3 per cent of the rock.

White talc was found on the surfaces of two small specimens. No estimate of quantity can be made.

Sample—DARK RIDGE C-1. This rock is composed of olivine, antigorite, talc, chlorite, and chromite and appears to have been nearly all olivine before alteration took place.

The olivine composes about 50 per cent of the rock. About half of the olivine is unaltered and occurs in crystals of 1 to 2 mm. in diameter. The other half of the olivine is highly shattered and shows extensive alteration to antigorite.

<sup>69</sup>Petrographic analysis made by W. Wirth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

The antigorite comprises 20 to 25 per cent of the rock. It is an alteration product of the olivine and also from some of the chlorite.

Talc makes up about 20 per cent of the rock. The origin of the talc was not determined. Some sections show inclusions arranged in a pattern similar to those of pyroxene, however, no remnants sufficient to identify the source of the talc were found.

The chlorite comprises about 10 per cent of the rock. Crystals were found throughout the rock but principally surrounding the chromite grains. Many of the crystals are partially serpentinized.

Only a small amount of chromite was found.

Sample—DARK RIDGE C-6. The principal constituent (about 90 per cent) of this rock is olivine. The crystals vary in size between 0.3 mm. (about 50 per cent) and 5 mm. in diameter with an average size of 1 mm. A good deal of the olivine is shattered, showing parallel cracks. A small amount of alteration to what appears to be chrysotile was observed in some of the olivine crystals.

A large per cent of talc was observed principally along veins; however, isolated masses were found. A few crystals of olivine appear to have altered to talc.

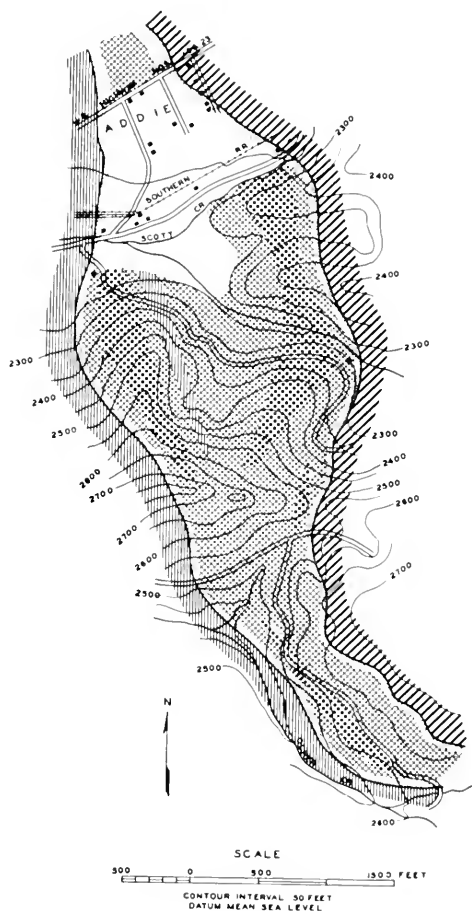
A vein of carbonate was observed in the rock. The carbonate appears to be an alteration product of the olivine and completely surrounds some of the small olivine crystals.

Chromite occurs in the olivine and appears to make up from 2 to 3 per cent of the rock. A few crystals of chlorite were observed.

#### THE ADDIE DEPOSIT






The Addie deposit occurs about 35 miles southwest of Asheville near the center of the Webster-Balsam area. This deposit extends three-fourths of a mile northwest and slightly more than one mile south of the railroad station at Addie. It is 2,000 feet wide at its widest point which occurs one-fourth of a mile south of the station (see Plate 24).

PLATE 24



ADDIE DEPOSIT

LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLende GNEISS

The Asheville-Murphy branch of the Southern Railway and also U. S. Highways Nos. 19 and 23 (parallel to the railroad) cross the northern end of the deposit. Several secondary roads cross the deposit at various points.

The Addie deposit is one of the largest in the Webster-Balsam area, and forms the eastern part of the great Webster-Balsam ring dike. This dike consists of a series of saxonite and dunite intrusions, which form an elliptical-shaped ring having a long axis of about six miles, and a short one of about three and one-half miles. The oldest dunites have been intruded by younger ones, and the whole mass later subjected to partial hydrothermal alteration. The geology of this dike is extremely complex, the details of which are beyond the scope of this report.

The Addie deposit, like others of the ring dike series, consists of a highly laminated dunite which on the weathered surface has an appearance of thin-bedded sandstone. These laminations, composed of concentrations of talc, chlorite, and other secondary minerals, are generally parallel to the formation contacts, and stand out as weather-resisting seams. Certain areas in the dunites, especially the later intrusions, suffered little metamorphism by hydrothermal solutions, and it is in these areas that the purest and highest grade olivine occurs.

The northwestern part of the deposit (not shown on Plate 24) consists of two steep-sided hills divided by a small stream. A pegmatite along the contact has altered the southern half of the formation, on the western side of the stream, to a soapstone of sufficient purity to be classed as talc. The northern part of this section, west of the stream, is a steep barren hill containing a thin residual clay underlain by two types of olivine. One is composed of gray-green interlocking crystals of medium-



grained olivine, partially altered to serpentine. The other is fine-grained, blue, highly laminated, tough olivine. Fine flakes of chlorite, scattered throughout the rock, greatly increase bonding strength.

On the east side of the small creek, the olivine rises in a bluff about 100 feet in height. The southern and southwestern part of this bluff consists mostly of coarse-grained, tough, gray-green, interlocking olivine. Near the northern and western part of the bluff there is a zone about 75 feet wide of medium-grained light green, granular and semifriable olivine which contains few accessory minerals and shows little signs of alteration to serpentine. The northern and eastern part of the formation, lying on the east side of the creek, has a rather heavy overburden, probably as much as 30 to 40 feet in most places.

The main body of the Addie deposit, much of which is known as the Fisher property, lies south of Scott Creek and north of Ocher Creek. This part of the deposit is characterized by rugged topography made up of steep-sided and narrow ridges divided by deep valleys.

Immediately south of the Fisher home is a steep ridge which rises from the valley floor and continues southward to Ocher and Scott Creek Gap. The northern half of this ridge, approximately 300 feet high, consists of good olivine which underlies an area about 1,500 feet long and 400 feet wide (see Plate 24). This olivine consists of both a coarse-grained, granular, interlocking crystalline type, and dark green, granular and friable material containing few accessory minerals except chromite.

Near the middle of the Addie deposit there occurs an inclusion of mica-schist (see Plate 24). Surrounding this inclusion is a partly serpentized dunite which contains many small seams filled with nickel silicate minerals.

An abrupt bluff of olivine 80 feet high occurs adjacent to Scott Creek a short distance east of the railroad station at Addie. This bluff continues as a long ridge southward for a distance of about 2,500 feet and has a width of approximately 500 feet (see Plate 24). The ridge is intersected by two small valleys at right angles to its long axis. Most of this ridge is underlain by olivine of the light green, coarse-grained, granular and friable type containing massive seams and disseminated crystals of chromite, the whole of which shows little indication of serpentinization. South of the ridge, the topography becomes rather steep and forms the Ocher-Scott Creek Gap, which is underlain mostly with a coarse-grained, interlocking crystalline type of olivine containing many small faults partly filled with vermiculite and asbestos.

The southern part of the formation narrows to about 400 feet in width and outcrops along a steep bluff overlooking Ocher Creek to the southwest. A gravel road passes along the center of this section of the Addie deposit; the best olivine occurs between the road and Ocher Creek. This part of the formation outcrops as a sheer bluff in which all the olivine is highly laminated. This laminated olivine, however, has retained a part of its original granular, friable character, and serpentinization is only visible upon close examination of the hand specimen. The olivine outcrops on the northeastern branch of the gravel road contains exceptionally closely spaced vermiculite veins, some of which are as much as two feet in thickness. The part of the formation between the road and Ocher Creek offers several excellent quarry sites in relatively sound olivine.

Much of the Addie deposit is nearly barren of vegetation and contains practically no overburden. In the areas of granular, fresh olivine, the boulders stand well above the general surface. This deposit offers exceptionally good quarrying possibilities, due to the large

reserve of high-grade olivine occurring adjacent to the railroad.

The Addie deposit contains 28,350,000 tons of relatively unaltered granular olivine and 102,450,000 of serpentinized dunite above Scott Creek level.

#### CHEMICAL ANALYSIS<sup>70</sup>

##### RELATIVELY UNALTERED OLIVINE FROM ADDIE DEPOSIT

Samples	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
A-1 .....	48.80	38.68	10.88	0.94	0.12	0.69
B-1 .....	48.64	39.14	10.40	1.14	0.08	0.85
C-1 .....	48.10	39.58	9.28	1.24	0.08	1.14
E-1 .....	46.82	37.40	11.52	1.60	0.20	1.77

#### P. C. E. VALUE

Sample A-1 from the Addie deposit has a P.C.E. value of 36 and Sample E-1 has a P.C.E. value of 35, which means the olivine has good P.C.E. value.

##### RELATIVELY FRESH TYPICAL SAXONITE FROM ADDIE DEPOSIT

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
A-1 .....	46.40	41.62	9.28	1.08	0.20	1.95

##### WEATHERED AND STEATITED DUNITE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
O.C-1 .....	42.96	41.86	10.24	1.76	0.22	2.36

<sup>70</sup> Chemical analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

PARTLY SERPENTINIZED DUNITE FROM GARLAND DILLARD  
PART OF THE ADDIE DEPOSIT

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
A-1	45.73	40.94	8.80	1.86	0.30	2.22
A-2	46.47	41.34	9.02	1.16	0.32	1.92
B-1	45.65	41.94	8.55	1.30	0.32	2.32
B-2	44.55	40.78	9.12	1.28	0.26	2.71
C-1	45.24	40.50	8.40	1.18	0.30	3.67

#### PETROGRAPHIC ANALYSIS<sup>71</sup>

Sample—ADDIE E-2. The chief constituents of the rock are fine-grained antigorite serpentine and carbonate (dolomite or magnesite) occurring in nearly equal amounts. Throughout the rock are high-refrinent remnants of an orthorhombic mineral which likely is olivine. The particles are too small to determine their composition definitely. It is rather difficult to estimate the relative amounts of this mineral; however, it is believed that it will amount to 15 to 20 per cent of the rock.

A few badly shattered crystals of chromite are also present.

Sample—ADDIE A-1. The principal constituent of this rock is olivine. It comprises about 90 per cent of the rock. The crystals of olivine vary in size between 0.1 and 2 mm. in diameter with the majority about 0.5 mm. Approximately half of the crystals are cracked. Many of the fissures are filled with serpentine. A few of the olivine crystals are partially altered to antigorite. Not over 2 per cent are so affected. The olivine is high in iron content as shown by the dark color of the rock and the presence of iron oxide with the antigorite. It is

<sup>71</sup> Petrographic analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

estimated that the antigorite amounts to about 5 per cent of the rock.

About 5 per cent of the rock was found to be chromite which occurs in 0.03 to 0.05 mm. euhedral crystals. A few crystals of chlorite were observed. The latter occur at the olivine-chromite boundaries.

Sample—ADDIE D-1. The principal constituent of the sample is olivine. The crystals are cracked but are only slightly altered to antigorite along the crystal borders, with the exception of those crystals in contact with the blue veins cutting through the rock. These latter crystals are altered to antigorite and chlorite.

About two-thirds of the vein material appears to be a mixture of antigorite, talc, and chlorite. The remaining third is largely bladed crystals of chlorite which penetrate into the margin of olivine crystals.

The extent of the alteration of the material will depend upon the frequency of occurrence of the veins. There are only two in the hand specimens.

The sample contains one to two per cent of chromite dispersed throughout the olivine.

#### P. C. E. VALUE

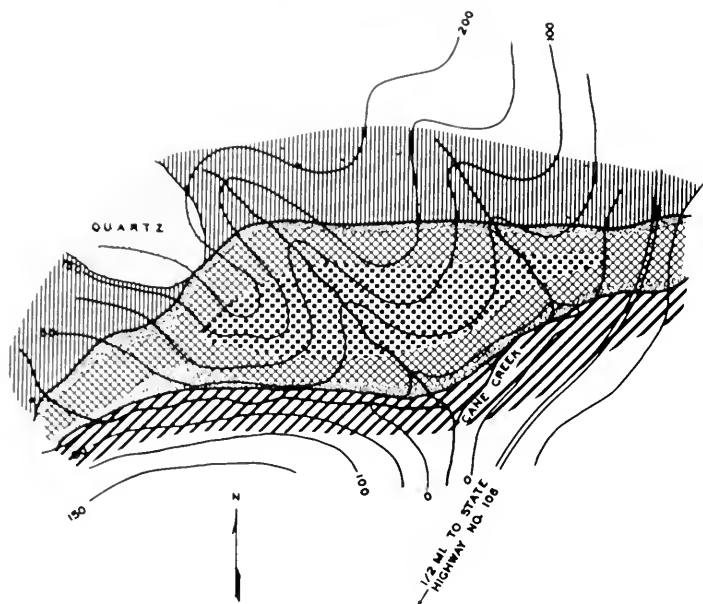
Sample Addie O.C. A-1 has a P.C.E. value of 35 to 36.

#### CANE CREEK OLIVINE DEPOSIT

The Cane Creek deposit, three and one-half miles southeast of Sylva, N. C., is located one-half mile up Cane Creek, due west of Rocky Face Mountain. The deposit outcrops on the west side of Cane Creek as a roughly lens-shaped body trending in an east-west direction for about 1,500 feet. It has a maximum width of approximately 300 feet. This deposit is a part of the Webster-Addie ring dike series.






Most of the formation consists of dunite outcropping on two barren hills, divided by Mary Hooper branch (see Plate 25). A part of the formation along the southern contact, consists of a coarse-grained inter-

PLATE 25



## CANE CREEK DEPOSIT

## LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLLENDE GNEISS

locking crystalline saxonite which has been highly laminated, and partly serpentinized. Talc blebs, altered from bronzite, are quite common throughout this part of the deposit. The central part of the formation consists mostly of coarse-grained, light green, friable and relatively sound olivine. Part of this friable material contains chromite crystals in such quantity that the weathered surface of the dunite has a black-spotted appearance. The formation contains very little overburden except residual clay and a few residual boulders. Vermiculite- and chlorite-filled faults paralleling the long axis of the olivine formation are rather conspicuous.

The Cane Creek deposit is rather small in size in comparison with some of the other deposits in the area. This deposit is located one-half mile from the Southeastern and Tuckasegee Railroad and has suitable topography and sufficient reserves of relatively high-grade olivine to support two medium-sized quarries. It is estimated that this deposit has 1,800,000 tons of relatively unaltered granular olivine and 3,100,000 tons of serpentinized dunite above Cane Creek level.

#### CHEMICAL ANALYSIS<sup>72</sup>

##### SERPENTINIZED SAXONITE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Cane Creek A-1.....	44.82	41.34	9.44	1.58	0.30	2.35

##### RELATIVELY UNALTERED OLIVINE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Cane Creek A-2.....	48.78	40.04	10.24	0.48	0.26	0.92

<sup>72</sup> Chemical Analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

**P. C. E. VALUE**

Sample Cane Creek A-2 has good refractory qualities because the P.C.E. value was found to be +35.

**PETROGRAPHIC ANALYSIS<sup>73</sup>**

Sample—CANE CREEK A-1. This rock is composed of 70 to 80 per cent olivine, 10 per cent or more of talc, several per cent of anthophyllite and chlorite, and a small amount of antigorite and chromite.

The olivine crystals vary in size between 0.1 and 1.0 mm. in length. The crystals are all shattered. The fractures appear to be filled with antigorite; however, it is so fine-grained that it is impossible to verify. Very few iron spots are seen along the altered edges, which would indicate that the olivine is low in iron content and approaches forsterite in composition.

The talc is distributed throughout the rock and also is found in small nodules or clumps up to 2 or 3 mm. in size. The talc forms the bulk of the filling and in places contains chlorite.

The blue-black spots have a highly shattered chromite grain in the center surrounded by bladed crystals of chlorite. The chromite is very black even in small fragments and shows very few brown edges. It may be assumed that the chromite is high in iron.

The anthophyllite may be the source of at least a part of the talc.

Sample—CANE CREEK A-3. This rock appears to contain at least 80 per cent olivine, 15 to 20 per cent of serpentine (largely antigorite), and 1 to 2 per cent chromite.

The olivine occurs in fairly large crystals, many measuring 2 to 3 mm. in diameter. The crystals are all quite badly shattered, thus reducing the effective size. The fracture and spaces between the crystals show alteration to antigorite. Many of the olivine crystals are almost entirely altered leaving only remnants of the original crystals.

<sup>73</sup> Petrographic analysis made by W. Wurth Kriegl, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.



The light green blades through the rock are mainly composed of antigorite with some remnants of olivine. Very little iron oxide is to be seen in the rock except in sections on the surfaces, which appear to be reddish in the hand specimens. Here, also, the olivine appears stained.

The chromite occurs in small scattered grains usually surrounded by antigorite. The chromite is very dark, and shows brown only on the very thinnest edges.

#### P. C. E. VALUE

Sample Cane Creek A-2 has a P.C.E. value of +35.

#### WEBSTER DEPOSIT

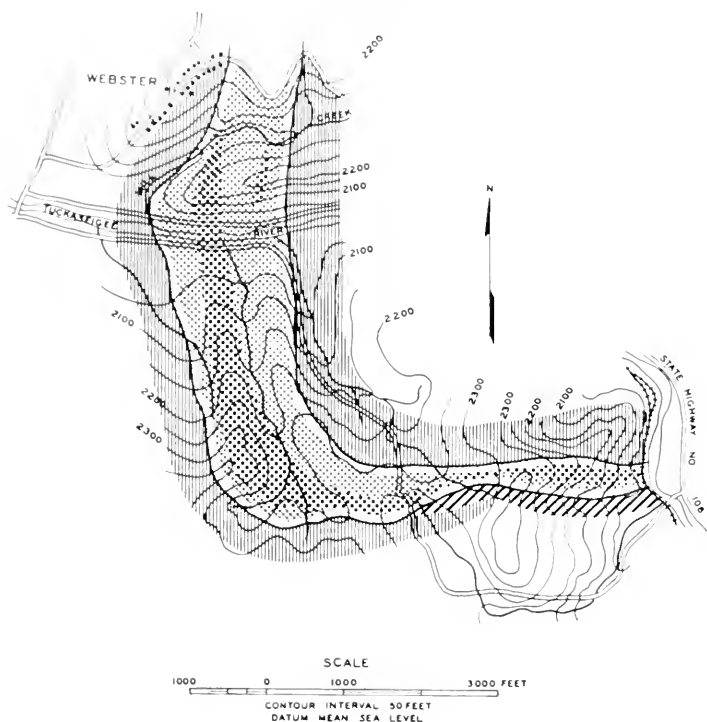
The Webster peridotite is located about two miles south of Sylva, Jackson County, North Carolina. It extends from a short distance north of Webster, southward through the town to a point three-fourths of a mile south of the Tuckasegee River; and then nearly due east for one mile to the Tuckasegee and Southwestern Railroad (see Plate 26). The deposit is roughly crescent-shaped, and has a length of two and three-fourths miles, and maximum width of 1,800 feet. This is the largest peridotite body exposed in the ring dike.

Most of the area consists of long, low, rolling ridges and wide valleys. However, the topography is quite rugged in the extreme eastern part, where the hills rise abruptly for about 250 feet above the valley floor. Just south of Webster, the rolling topography is again broken by a steep bluff 150 feet high, which parallels the northern bank of the Tuckasegee River. About one-fourth of the deposit, especially the uplands, is covered by transported clays, river gravels, and thick-residual soil. The best exposures of olivine are on the bluff overlooking the river.

Apparently this formation is made up of a series of intrusions which have undergone various degrees of alteration, mostly caused by invading pegmatitic solu-






tions. Along the eastern rim is a highly faulted and fractured zone in which the dunite is badly weathered and serpentized. Several minor faults cut through the deposit in various directions, and on either side of these the rocks show signs of alteration. Typical of others in the ring dike, this deposit is highly laminated.

PLATE 26



## WEBSTER DEPOSIT

## LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLLENDE GNEISS

The Webster deposit consists, for the most part, of a medium-grained, fairly sound, granular, green olivine, which usually shows a slight amount of serpentinization. This rock occurs as a band occupying about 75 per cent of the western and southern half of the deposit, and extends from just south of Webster to the eastern end of the deposit. Crystals of chromite have been concentrated in pockets and lenses within the band of dunite. Some of these concentrations, especially those near the eastern end of the deposit, have been mined to a limited extent. More chromite float is visible on the Webster formation than on any other dunite in the belt.

Websterite, a variety of saxonite composed mostly of green diopside and brown bronzite, occurs as a band about 200 feet wide, just east of the unaltered dunite zone. This rock is rendered quite conspicuous by its bright grass-green color, extremely large grain size, and numerous bronzite crystals. (For analysis, see page 95.) The Websterite probably represents one of the later peridotite intrusions of the ring dike series. At present, this rock is of little commercial value.

A badly weathered serpentinized olivine rock which has been fractured and faulted, occurs along the eastern rim of the formation. Nickel, occurring as silicate minerals, fills many of the cracks and faults in the rock. This nickelized zone, averaging 1.5 per cent  $\text{Ni}^{+1}$  extends nearly the entire length of the deposit, and attains a maximum thickness of 300 feet near the old Nickel Plant, just south of the river.

The Webster deposit has several suitable quarry sites in the semi-fresh granular olivine. Probably the best of these sites is just south of Webster, along the bluff on the north side of Tuckasegee River. Most of the western end of this bluff is composed of a fairly sound olivine,

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<sup>71</sup> G. W. Pawel, "Nickel in North Carolina," *Engineering and Mining Journal*, October 1939, p. 35.

with little overburden. Another good site is located in the extreme eastern end of the formation, near the Tuckasegee and Southwestern Railroad. Here the olivine is of the light green granular type, and is associated with pockets of chromite. Several other quarry sites are located throughout the formation.

Using the Tuckasegee River as base level, the Webster deposit is estimated to contain 58,150,000 tons of relatively unaltered granular olivine, and 167,890,000 tons of serpentinized dunite.

#### CHEMICAL ANALYSIS

##### RELATIVELY UNALTERED OLIVINE

Sample <sup>75</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Webster A-1 N	45.32	41.38	9.28	1.26	0.20	1.97

##### RELATIVELY UNALTERED OLIVINE AND CHROMITE

Sample <sup>75</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Webster G. C. B-1	36.41	27.38	12.48	19.31	0.22	3.26

##### PARTLY ALTERED SAXONITE

Sample <sup>75</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Webster B-1 N	46.42	41.82	9.12	1.14	0.18	1.55

##### SERPENTINIZED AND WEATHERED DUNITE

Sample <sup>75</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Webster B-1	42.82	37.04	8.72	1.14	0.32	9.17

<sup>75</sup> Chemical Analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

## SERPENTINIZED DUNITE

Sample <sup>76</sup>	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Webster A-1.....	44.08	39.98	8.00	2.36	0.20	4.41

WEBSTERITE FROM WEBSTER, N. C.<sup>77</sup>

MgO	SiO <sub>2</sub>	CaO	FeO	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	H <sub>2</sub> O	Cr <sub>2</sub> O <sub>3</sub>
26.66	55.14	8.39	4.73	3.48	0.66	0.38	0.25

WEBSTERITE FROM WEBSTER, N. C.<sup>77</sup> (Cont.)

P <sub>2</sub> O <sub>5</sub>	NiO	MnO	Na <sub>2</sub> O	TiO <sub>2</sub>	Total
0.23	0.11	0.03	0.30	Trace	100.36

## P. C. E. VALUE

Samples Webster B-1N and Webster B-1 have P.C.E. values of +35, which is higher than would be expected from the chemical analysis.

## PETROGRAPHIC ANALYSIS

Petrography of Webster Dunite.<sup>78</sup>

This rock consists of an even-grained crystalline olivine, with more or less chromite disseminated through the mass in small grains and crystals. In texture the olivine varies from almost invisible grains to very coarse-grained masses, with occasional individuals an inch or more in diameter. The more common occurrences are somewhat coarser grain than loaf sugar.

The least altered portions have a light to dark yellowish green or grayish green color, an oily to vitreous lustre, and an uneven, angular fracture. Weathering gives rise to all gradations of color from that of the fresh rock to the characteristic yellowish or reddish brown of the barren out-

<sup>76</sup> Chemical Analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>77</sup> Websterite analysis from Pratt and Lewis, *op. cit.*, p. 97.

<sup>78</sup> Pratt and Lewis, *op. cit.*, p. 92.

crops. . . . Transparent colorless, allotriomorphic olivine grains constitute the mass of the rock. Chromite in scattering crystals or irregular grains is a constant accessory . . . .

In the great majority of cases, even when the hand specimens look perfectly fresh, the olivine is found to have altered somewhat to serpentine, with sometimes more or less talc, chlorite, etc. Hence the olivine grains are usually completely separated from one another by these secondary products. In many specimens, however, the alteration has been very slight; and, in a few sections, only traces of serpentine are to be found. The olivine is transparent and colorless, and exhibits typical optical characteristics. . . . It is only in a somewhat advanced stage of alteration that the corners become rounded and the section under the microscope assumes the appearance of rubble masonry. In the fresh specimens the olivine grains are often broken by irregular fractures. . . . With the beginning of alteration to serpentine, however, the increase in volume gives rise to stresses that greatly increase the irregular fracturing and frequently develop regular cleavage cracks in considerable numbers. . . . Chloritization, a mode of alteration much less common than serpentinization, is well represented in portions of the Webster dunite. . . .

Sample<sup>79</sup>—WEBSTER B-1 N. The sample consists of 80 to 90 per cent olivine, 10 per cent or more of enstatite and/or bronzite, several per cent of antigorite serpentine, a small amount of chromite, and a trace of chlorite.

The olivine crystals are from 0.3 to 2 mm. in diameter, and are somewhat fractured. Antigorite surrounds the grains and fills the fractures.

The pyroxene is largely enstatite; however, a portion of it appears to be the ferruginous form, bronzite. The pyroxene is dispersed quite evenly throughout the rock. There is evidence of some serpentinization of this mineral.

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<sup>79</sup> Petrographic Analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

The antigorite does not appear to be concentrated in any large areas but fills around the other minerals in thin crystals oriented parallel to the fracture and crystal boundary lines.

The chromite appears to be small in amount and rather low in iron content. It occurs in the olivine but is frequently surrounded by crystals of chlorite.

Sample<sup>80</sup>—WEBSTER G. C. A-1. The sample consists of 50 to 60 per cent olivine, 30 to 40 per cent antigorite, 4 to 8 per cent chlorite, 4 to 8 per cent carbonate (likely dolomite), a small amount, perhaps one per cent of talc, one per cent or less of chromite, and a small amount of limonite. Because of the great variance of sections, the percentages are approximations.

The olivine appears to be rather iron free and must approach forsterite in composition. All of the crystals are shattered and few are not highly disintegrated. Only remnants of many remain.

The carbonate appears to have replaced olivine. They showed no effervescence with hydrochloric acid. It is therefore assumed to be dolomite or magnesite.

The serpentine is largely antigorite. The mineral appears to be the chief alteration product of the olivine. It surrounds all olivine grains.

The chromite occurs in fairly large but badly shattered grains surrounded by chlorite. Chlorite also occurs in small isolated aggregates.

#### P. C. E. VALUE

Sample Webster G. C. B-1 has a P.C.E. value of +36.

Sample Webster B-1 has a P.C.E. value of +35.

Sample Webster B-1 N has a P.C.E. value of +35.

Several other deposits of granular olivine occur in the Webster-Balsam area, but are not described here because of their poor location in relation to transportation. The best of these occurs near the headwaters of Cane Creek.

<sup>80</sup> Petrographic Analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

### ELLIJAY AREA

The Ellijay area, about 15 miles long and 8 miles wide, is located approximately 55 miles southwest of Asheville, N. C. and a few miles east of Franklin, N. C. It extends from the northwestern part of Rabun County, Georgia, northeastward through Macon County, N. C., and into Jackson County, N. C. (see Plate 8).

In general the topography is quite rough. The southwestern part of the area consists of high rounded hills and fairly wide valleys, while the northeastern part extends into the rugged Blue Ridge mountains. The entire drainage is by the Little Tennessee River which flows through the center of the area.

Olivine deposits are scattered throughout the area, with the most important ones located within 3 miles of Ellijay Post Office. This report describes only those which are accessible to adequate transportation facilities, namely, Moores Knob, Ellijay Creek, Number 9, Corundum Hill, and Norton. These deposits contain an estimated 20,020,000 tons of relatively unaltered olivine, and 56,340,000 tons of serpentized dunite.

The area is crossed by the Tallulah Falls Branch of the Southern Railway, and several federal highways. Many secondary roads make transportation fairly easy throughout the area.

### MOORES KNOB DEPOSIT

The Moores Knob Dunite, three-fourths of a mile northeast of Ellijay, Macon County, N. C., is the largest deposit in the area. It is roughly lens-shaped, with minor and major axes of 1,000 and 3,000 feet respectively. Berry Prong of Ellijay Creek flows along the eastern and southern contacts of the formation.

The deposit outcrops as a spur, which rises abruptly from the north side of the creek to a height of about 200 feet and continues northeastward at a steep grade to Ammon's Ridge, where it attains a height of about 400



feet. Overburden is relatively light except in the north-western part of the area, where a thick red residual soil containing much soapstone float covers the rock.

This olivine occurs as a dunite which has undergone some alteration. Most of the eastern quarter of the formation consists of relatively fresh, yellowish-green, coarse-textured, granular olivine; while that near the southwestern nose is fine-grained, light green, and somewhat friable. The remainder of the deposit consists of steatized and chloritized dunite. This formation is estimated to contain 14,000 tons of relatively unaltered granular olivine and 42,000,000 tons of serpentinized dunite above Berry Prong of Ellijay Creek.

Many years ago this deposit was worked for corundum. Recently these old workings have been reopened and many new shafts and tunnels driven into the formation for the production of vermiculite. This mineral is quite abundant, occurring as veins and lenses throughout the deposit.

#### CHEMICAL ANALYSIS<sup>81</sup>

##### RELATIVELY UNALTERED OLIVINE

Samples	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Moores Knob B-1	49.48	39.52	9.28	1.12	0.05	0.08

##### CHLORITIZED DUNITE

Samples	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Moores Knob A-1	45.50	42.06	9.76	1.06	0.10	1.43
Moores Knob S-1	46.60	41.64	7.50	2.16	0.34	0.71

#### P. C. E. VALUE

Sample Moores Knob A-1 has a P.C.E. value of 36-37.

<sup>81</sup> Chemical analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

**ELLIJAY CREEK DEPOSIT**

The Ellijay Creek dunite—about one-half mile northwest of Ellijay Post Office, is just east of the point at which Berry Prong enters the main Ellijay Creek. The deposit is semicircular in shape and rises from creek level to a height of about 50 feet. This is one of the smallest deposits, and has an outcrop length of only 500 feet and a maximum width of 200 feet. The formation has been partly exposed on the southern side adjacent to the creek by recent vermiculite mining.

The olivine occurs as a fresh, light green, granular, friable dunite, about half of which has undergone alteration. This deposit is estimated to contain 315,000 tons of relatively sound olivine and about an equal amount of serpentinized dunite.

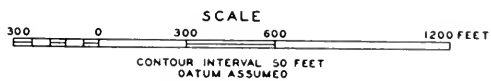
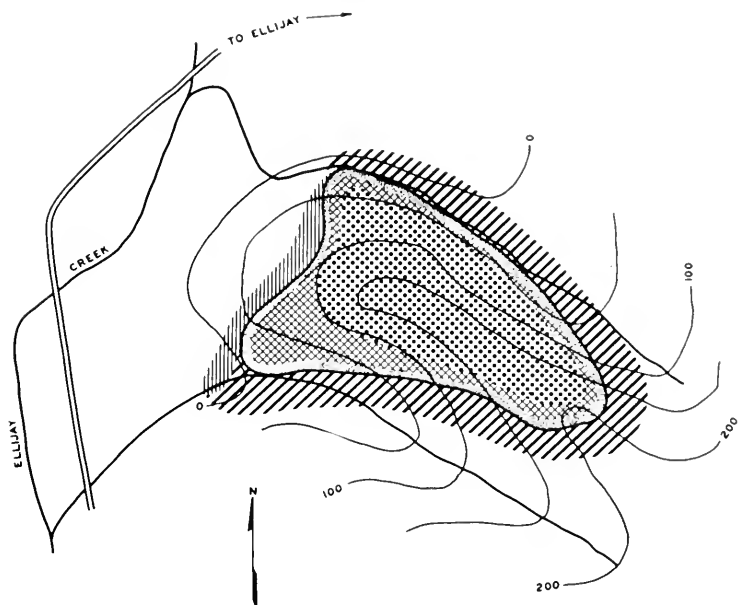
**DEPOSIT NUMBER NINE**

Deposit Number Nine occurs one-half mile southwest of Ellijay Post Office and a short distance east of Ellijay Creek. This occurrence is about five miles east of Franklin, North Carolina. The deposit outcrops along the crest and on the north and south side of a low ridge which rises about 200 feet above Ellijay Creek.

This deposit is heart-shaped with the long axis slightly more than 1,000 feet long and the width at the blunt end nearly 1,000 feet (see Plate 27). This formation is made up of medium-grained dunite containing light green, fresh, friable olivine. The deposit is thickly intersected with small faults filled with exceptionally high grade, light green vermiculite. Some of these veins have been worked rather extensively.






Near the southern extremity of this deposit, there occurs a concentration of massive chromite in small veins, but the most chromite occurs on the northern side of this formation in the form of disseminated crystals in a matrix of granular olivine. Little serpentine can be detected in the hand specimens of the dunite.

## PLATE 27



## DEPOSIT NO. 9

## LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLLENDE GNEISS

Although the deposit is not the largest in the Ellijay area, it may well be one of the most important because of its high grade and uniform olivine. The Number Nine deposit contains 5,020,000 tons of relatively sound olivine and 7,020,000 tons of serpentinized dunite above creek level.

#### CHEMICAL ANALYSIS<sup>82</sup>

##### RELATIVELY UNALTERED OLIVINE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Number Nine A-1 ...	47.50	38.94	10.88	1.36	0.08	0.89
Number Nine B-1....	47.96	39.20	11.20	1.34	0.22	1.01

#### P. C. E. VALUE

Sample Deposit Nine B-1 has a P.C.E. value of 35 to 37.

#### PETROGRAPHIC ANALYSIS<sup>83</sup>

Sample—DEPOSIT NINE B-1. The rock contains 80 to 90 per cent olivine. The crystals are all quite large, many measuring 2 or 3 mm. in diameter; however, they are all quite badly shattered. The larger fractures are filled with chlorite. The smaller fractures are filled with chrysotile. Small areas of olivine show serpentinization to antigorite.

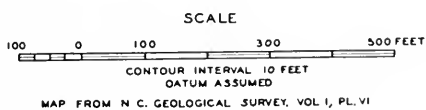
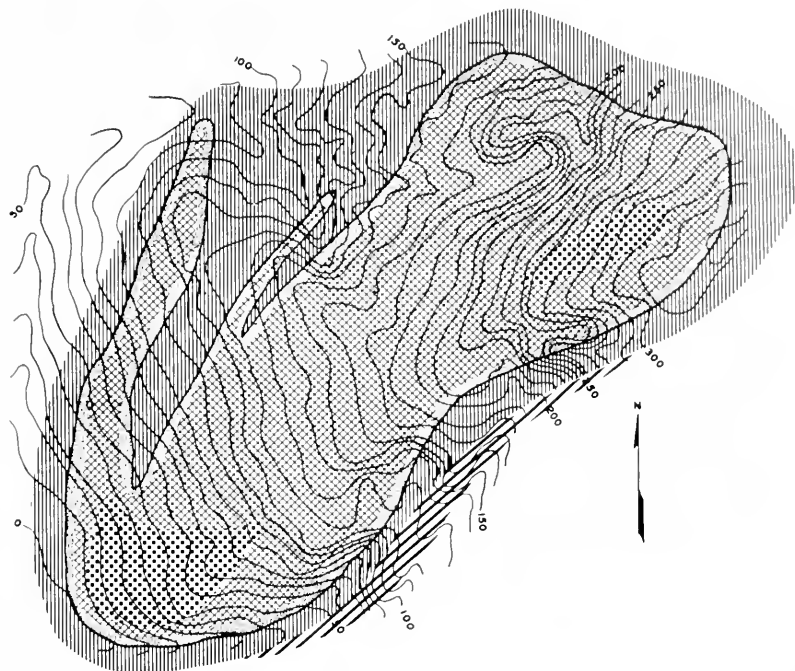
Fairly large areas of chlorite are found in zones of fracture. A few chlorite crystals are found at the olivine boundaries, and they appear to be an alteration product of the olivine.

Chromite occurs in many small crystals scattered throughout the rock. The average size is about 0.03 mm. in diameter with a few larger crystals about 0.4 mm. in diameter. All are surrounded by bladed crystals of chlorite.

<sup>82</sup> Chemical analysis by TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>83</sup> Petrographic analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

## PLATE 28



## CORUNDUM HILL DEPOSIT

## LEGEND

- RELATIVELY UNALTERED GRANULAR OLIVINE
- SERPENTINIZED DUNITE
- TALCY VERMICULITE FRINGE ZONE
- BIOTITE SCHIST
- HORNBLende GNEISS

**THE CORUNDUM HILL OLIVINE DEPOSIT**

The Corundum Hill olivine deposit occurs six miles southeast of Franklin and one and one-fourth miles northwest of Gneiss. It forms a rounded hill a short distance southeast of Evans Knob and one-half mile north of U. S. Highway 64.

The Corundum Hill deposit is no doubt the most famous dunite formation in the entire country. The whole deposit is honeycombed with old corundum workings. It was here that corundum was first produced in the United States and that many of the fine corundum and gem specimens now in the National Museum were mined.

This deposit is approximately 1,200 feet long and averages 500 feet wide. At its northeastern end and its southwestern end, this formation is rounded and blunt in shape, and in this respect is somewhat different from the other dunite formations occurring in the Appalachian area (see Plate 28). The formation contains several schist inclusions, especially near the northwestern contact zone. Some of these inclusions show evidence of having been faulted into place. Much of the deposit outcrops as a barren rounded hill.

The Corundum Hill deposit consists entirely of dunite, part of which has been serpentinized. Near both ends of the formation the dunite is composed of coarse-grained, yellowish, granular olivine, much of which appears to be rather sound. Parts of the dunite, especially near the faults, are highly serpentinized and at a few places near the schist inclusion nickel silicate minerals are visible.

The contact zones and many of the interior faults in the deposit are filled with vermiculite. This deposit has produced vermiculite intermittently since 1933.

Note in the next analysis chart that the Corundum Hill olivine contains a rather high percentage of mag-

nesia which should make the material desirable for use in a chemical process. Two parts of the deposit offer good quarry sites in rather sound olivine. Corundum Hill deposit is estimated to contain 700,000 tons of relatively sound olivine and 6,970,000 tons of serpentinized dunite above creek level.

#### CHEMICAL ANALYSIS<sup>84</sup>

##### RELATIVELY UNALTERED OLIVINE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Corundum Hill A-1	49.35	40.58	8.30	0.65	Trace	1.13
Corundum Hill C-1	48.62	41.50	7.52	0.50	Trace	1.19
Corundum Hill F-1	48.57	40.20	7.66	1.94	0.00	1.42

##### PARTLY SERPENTINIZED DUNITE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Corundum Hill B-1	45.46	41.60	8.46	1.70	Trace	2.61
Corundum Hill D-1	47.32	41.10	8.70	0.48	Trace	2.87
Corundum Hill E-1	47.70	40.94	8.06	1.03	Trace	2.52

#### P. C. E. VALUE

Sample Corundum Hill A-1 has a P.C.E. value of +35.

#### PETROGRAPHIC ANALYSIS<sup>85</sup>

Sample—CORUNDUM DUNITE. "The fresh rock is of various shades of yellowish green, according to physical and chemical conditions. . . . Olivine is the only abundant constituent of the rock, varying in texture from very fine to medium coarse, with occa-

<sup>84</sup> Chemical analysis by TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>85</sup> Petrographic analysis from Pratt and Lewis, *op. cit.*, p. 86.

sional individuals measuring half an inch or more in diameter. . . . The olivine greatly exceeds all other minerals in abundance. It presents all degrees of alteration to serpentine, only in rare cases appearing perfectly fresh. It is also rarely the case that more than half of the mineral has been altered. . . . The olivine in the unaltered sections . . . is perfectly transparent and colorless. . . . [The grains vary] in size from 0.5 mm. to 12.0 mm. in diameter. The enstatite, which is found in most of the sections, occurs in nearly square or somewhat elongated sections of the prism zone . . . [and] in the great majority of cases it is also perfectly fresh. . . ."

#### NORTON DUNITE DEPOSIT

The Norton dunite occurs 14 miles south of Franklin and one mile north of the North Carolina and Georgia state line. This deposit occurs on the north side of Commissioners Creek and one mile west of Tallulah Falls railroad. The deposit forms a rugged hill overlooking the creek.

This deposit contains little true olivine as it is composed mostly of anthophyllite asbestos and chlorite. The formation is nearly circular with a diameter of nearly 500 feet. The top of the formation is estimated to be 300 feet above creek level.

The Norton deposit is estimated to contain 10,000,000 tons of altered dunite above creek level.

#### CHEMICAL ANALYSIS<sup>86</sup>

##### AMPHIBOLIZED AND CHLORITIZED DUNITE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Norton A-1.....	39.04	43.62	10.24	2.20	1.32	2.20

#### P. C. E. VALUE

Sample Norton A-1 has a P.C.E. value of 20-23.

<sup>86</sup> Chemical analysis by TVA Minerals Testing Laboratory, Norris, Tennessee.



**PETROGRAPHIC ANALYSIS<sup>87</sup>**

Sample—NORTON A-1. The rock appears to have been an olivine which has been highly altered. Remnants of what appears to be olivine were found. The principal alteration product is chlorite, making up 40 to 50 per cent of the rock.

A fibrous mineral with typical amphibole cross-section cuts across the other minerals. The parallel extinction of the fibers would indicate that it is anthophyllite. The rock contains 15 to 20 per cent of this mineral.

Small euhedral crystals of magnetite, estimated at about 5 per cent are distributed throughout the rock. A small amount of talc was also observed.

There are many other olivine deposits occurring in the Ellijay area but the few described here are the most accessible and most typical. The best of the others occur on Higdon Mountain and in the headwaters area of Walnut Creek and Little Buck Creek.

**BUCK CREEK-SHOOTING CREEK AREA**

The Buck Creek-Shooting Creek area is estimated to contain 325,000,000 tons of serpentized dunite and 60,000,000 tons of relatively sound olivine.

The Buck Creek-Shooting Creek area is located about 100 miles southwest of Asheville, N. C. This area extends from the central part of Towns County, Georgia, to near the Clay-Macon County line in North Carolina. The area, which is about 13 miles long and 7 miles wide, extends from Hiwassee, Georgia, to Rainbow Springs, N. C. The eastern part of the area is drained by the Nantahala River, the central by Shooting Creek, and the southwestern by the Hiwassee River; all of which are tributaries of the Tennessee River.

The topography of the area consists of broad valleys and rolling hills for the central part and rugged mountains for the southwestern and northeastern part. Most

<sup>87</sup> Petrographic analysis by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, North Carolina.

of the eastern half of the Buck Creek-Shooting Creek area is above 4,000 feet in elevation.

A branch line of the Southern Railway serves Hayesville, N. C., located about three miles west of the central part of the area. U. S. Highways 64 and 76 pass through the area.

#### **BUCK CREEK DEPOSIT**

The Buck Creek dunite is located in the eastern part of Clay County, N. C., 25 miles east of Murphy, N. C. This deposit occurs two and one-half miles up Buck Creek and near the top of the rugged Nantahala Mountains. U. S. Highway 64 passes over part of the southern corner of the formation.

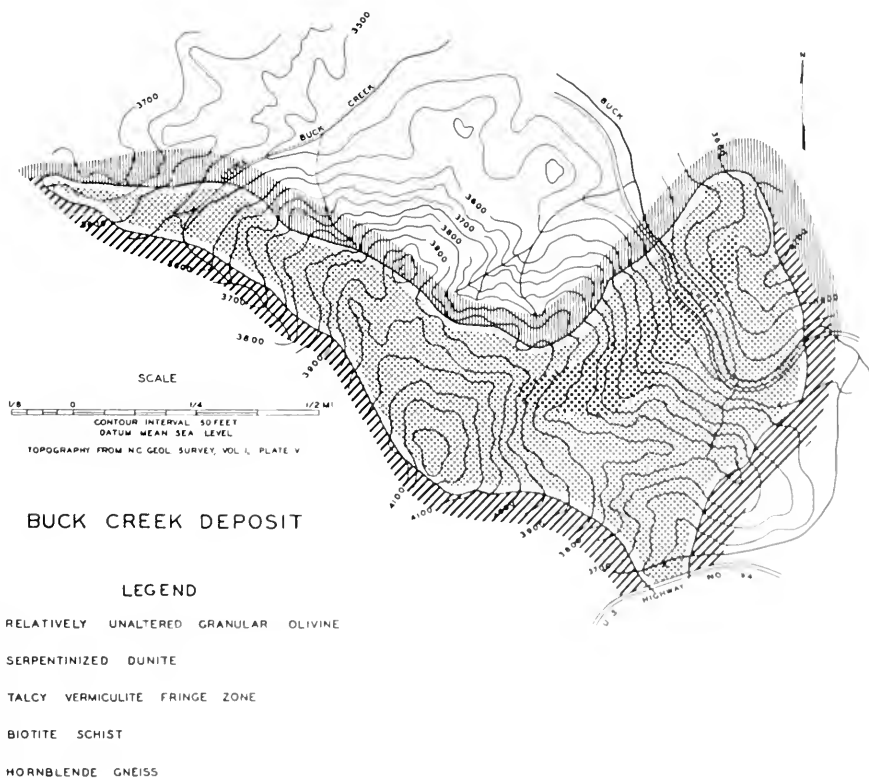
The Buck Creek deposit is the largest single outcrop of dunite in the entire olivine belt. This deposit is 4,500 feet wide at the eastern end and tapers to a narrow fringe at the western end. It has a length of about one and one-half miles. The topography of the deposit is rather rugged, as much of it is dunite cliffs. Part of the formation rises to more than 700 feet above Buck Creek, which is carved as a gorge near the eastern part of the formation.

The Buck Creek dunite consists of a series of intrusions, some of which have undergone much alteration. The deposit is cut by many small pegmatites which aided in alteration of parts of the dunite into chlorite. However, part of the deposit has remained relatively sound. Near the middle of the steep outcrop rising to the west of Buck Creek there occurs a zone about 250 feet wide of semigranular and partly friable olivine. This zone extends from near Buck Creek westward to Smaragdite Hill, a distance of about 2,000 feet (see Plate 29). Many of the samples taken from within this zone show only a small amount of alteration to serpentine and other minerals.

A conservative estimate of 300,000,000 tons of dunite above Buck Creek is made for the deposit. The tonnage of rather fresh, granular olivine for this deposit is estimated at 52,820,000 tons. The Buck Creek olivine deposit is by no means the best one in the area, but it is important because of its enormous size and its location only 30 miles from the TVA Hiwassee Dam and only 10 miles from one of the large Nantahala Power plants of the Aluminum Company of America.

Other deposits of dunite occur in this area, mainly in the southern end. Some of the deposits in the vicinity of Hiwassee, Towns County, Georgia, contain fairly good olivine but they were not mapped or sampled, because

PLATE 29



of inaccessibility of the deposits from a commercial production standpoint.

#### CHEMICAL ANALYSIS<sup>88</sup>

##### SERPENTINIZED DUNITE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Ti, Cr, Al, (Oxides)	CaO	Ign. Loss
Buck Creek A-1	46.52	38.70	10.70	2.52	0.56	1.77

#### P. C. E. VALUE

Sample Buck Creek A-1 has a P.C.E. value of 35 to 37.

#### PETROGRAPHIC ANALYSIS

Sample<sup>89</sup>—BUCK CREEK DUNITE. The dunite in the unaltered portions is light yellowish green to dark oil-green in color and of medium to fine-grained texture. It frequently possesses a laminated structure similar to that of the Webster dunite, though this character is by no means constant. In the various stages of serpentinization it becomes dark-green to greenish or brownish black. Black grains of chromite can generally be seen in the hand specimen. On the weathered surfaces the dunite of this area is very similar to that of the other districts throughout the region, and presents the characteristic dark brown or dun color, except where very much serpentinized, and in such places it is nearly black.

The microscopic character of the dunite is reported as follows: The rock consists essentially of olivine with small, variable amounts of green and colorless amphibole, chromite, and magnetite. In a great majority of the sections studied, alteration has given rise to one or more of the secondary products—serpentine, talc, chlorite, carbonates, and iron oxides.

<sup>88</sup> Chemical analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>89</sup> Pratt and Lewis, *op. cit.*, p. 73.

The olivine is perfectly colorless in the thin section and never shows crystal boundaries. It is generally cracked irregularly, particularly in the beginning of the change to serpentine. . . . The grains usually average from 0.5 mm. to 1 mm. in diameter, though isolated individuals of 5 mm. to 6 mm. are sometimes seen. With the exception of occasional rounded grains of chromite, the olivine is entirely free from primary inclusions. . . . With the beginning of alteration the borders and portions along the cracks often become clouded with dustlike or granular segregations of iron oxides.

The larger iron oxide spots are almost invariably associated with lath-shaped or confused aggregates of chlorite. In some cases the olivine alters extensively to chlorite, which penetrates the grains generally along the cleavage cracks first, though frequently in diagonal directions, in long slender laths, sometimes passing uninterruptedly through two or three grains.

Sample<sup>90</sup>—BUCK CREEK A-2. The principal constituent of this rock is olivine, which amounts to about 70 per cent of the rock. About one-third of the olivine is highly shattered and altered to antigorite. The olivine crystals vary in size from 0.3 mm. to 5 mm. with the majority about 1.5 mm. to 2 mm. in diameter.

Between 15 and 20 per cent of the rock is composed of antigorite, which is apparently largely derived from the olivine and is found cutting through olivine crystals. Some of the antigorites is derived from chlorite. The antigorite appears nearly iron free, thus indicating that the olivine is a low-iron mineral approaching forsterite in composition.

The chromite is much less in amount than would appear from the hand specimens, and amounts to only a few per cent. The majority occurs as skele-

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<sup>90</sup> Petrographic analysis by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, N.C.

ton crystals in large crystals of chlorite. A lesser amount was found as small crystals in the olivine.

The chlorite amounts to about 10 per cent of the rock and occurs only with the chromite as already mentioned.

Thin black veins in the hand specimens appear to contain a high concentration of limonite.

### **BURTON LAKE AREA**

The Burton Lake area occurs in a rugged part of the Blue Ridge Mountains about six miles west of Clayton, Rabun County, Georgia. This is a small area drained by the Tallulah River whose waters flow into the Atlantic. The area is crossed by U. S. Highway No. 76, and the Tallulah Falls Railroad passes through Clayton, Georgia.

### **THE BURTON LAKE OLIVINE DEPOSIT**

The Burton Lake olivine deposit occurs near the western part of the area 12 miles west of Clayton, Ga., and 30 miles southeast of Murphy, N. C.; U. S. Highway No. 76 passes over the deposit. This deposit is about 2,600 feet long and 800 feet wide outcropping mainly south of the highway along the sides and crest of a sharp ridge. The part of the formation on the north side of the highway forms a steep slope facing away from the road.

This whole deposit is of inferior dunite because of the high lime and iron content (see following analysis). Much of the dunite in this deposit shows serpentinization in the hand specimens. Near the central part of the western slope of the south ridge pyrite occurs in the olivine, which is the only occurrence noted in the area covered by this survey. This deposit contains several interior faults which have been partly prospected for slip fiber asbestos. Olivine in this deposit might be suitable for chemical use.

**CHEMICAL ANALYSIS**<sup>91</sup>**PARTLY ALTERED DUNITE**

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Burton Lake A-1.....	45.54	37.80	13.44	1.92	0.18	2.03

**PARTLY ALTERED PYROXENITE**

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Burton Lake B-1.....	20.40	50.80	6.56	1.78	19.82	1.29

**P. C. E. VALUE**

Sample Burton Lake B-1 has a P.C.E. value of —21.

**PETROGRAPHIC ANALYSIS**<sup>92</sup>

Sample—BURTON LAKE B-1. The principal constituent of this rock is the pyroxene, diopside, which comprises about 90 per cent of the rock. The rock is for the most part fine-grained, being made up of crystals 0.1 mm. or less in diameter with a few larger crystals about 1 mm. in diameter. The larger crystals show partial alteration to what appears to be antigorite. The smaller crystals show a small amount of alteration in a few fields to one of the hornblendes, probably actinolite.

Scattered throughout the rock are many very small crystals of magnetite. It is estimated that the magnetite constitutes from 3 to 5 per cent of the rock. A small amount of chlorite was also observed.

**THE LAUREL CREEK AREA**

The Laurel Creek area is located in the northeastern part of Rabun County, Georgia. The area is in mountainous territory on the eastern slopes of the Blue Ridge

<sup>91</sup> Chemical analysis by TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>92</sup> Petrographic analysis by W. Wirth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, N. C.

near the point where the South Carolina, Georgia, and North Carolina state lines join. The entire area is drained by Wowoman Creek and other tributaries of the Savannah River which flows into the Atlantic. The area is crossed by U. S. Highway No. 28 and several good National Forest roads. The nearest railroads are at Clayton, Ga., 15 miles to the west, and at Walhalla, S. C., 15 miles to the southeast.

#### THE LAUREL CREEK OLIVINE DEPOSIT

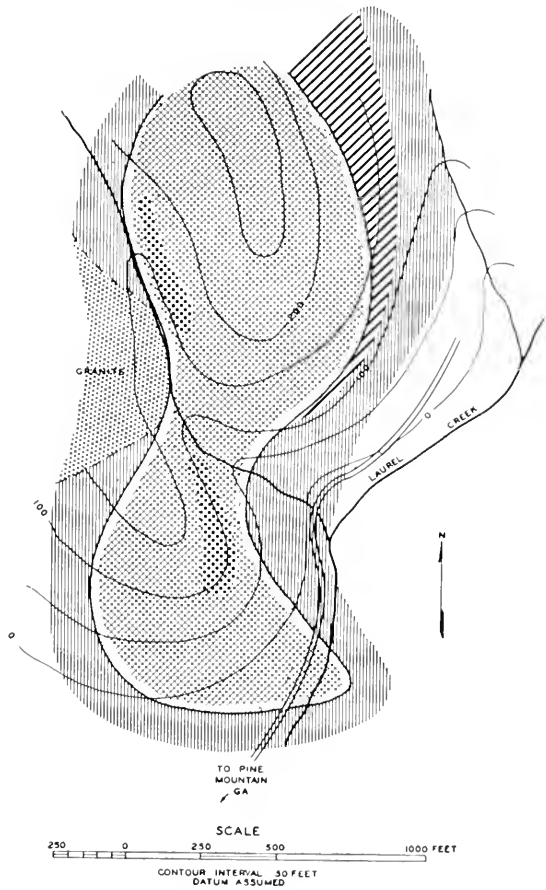
The Laurel Creek dunite occurs about one and one-half miles east of Pine Mountain, Georgia. This dunite body is about 2,500 feet long and averages about 1,200 feet wide; and outcrops in the form of two rounded masses joined by a narrow neck (see Plate 30). The topography of the deposit is essentially bluffs of olivine facing Laurel Creek, except where several small tributaries of Laurel Creek have cut small gorges across the formation.

The northeastern part of the Laurel Creek olivine deposit is the largest part of the formation and rises about two hundred feet above creek level. Most of the olivine is a relatively fresh and coarse-grained granular type; however, it probably contains 20 per cent talc and anthophyllite asbestos which is uniformly distributed through the mass. With these minerals so thoroughly mixed with the olivine, it is doubtful that the deposit will be of value as a source of olivine in the near future.

The western hill of this olivine deposit, covered with boulders and thin residual soil, rises about 100 feet above Laurel Creek. The southeast side of this mass is altered to a bluish serpentine but the central part is composed of relatively sound interlocking crystalline olivine. The material shows serpentinization along joints and cracks and it is likely that many of the individual grains are partly serpentinized. This part of the deposit shows few secondary minerals.








PLATE 30



LAUREL CREEK DEPOSIT

LEGEND

-  RELATIVELY UNALTERED GRANULAR OLIVINE
-  SERPENTINIZED DUNITE
-  TALCY VERMICULITE FRINGE ZONE
-  BIOTITE SCHIST
-  HORNBLende GNEISS

The Laurel Creek dunite deposit probably contains the best olivine in the state of Georgia, as it shows less alteration than any other deposit examined in Georgia. The deposit has favorable topography for quarry sites and it is estimated that the formation contains, above Laurel Creek level, about 1,440,000 tons of relatively unaltered olivine and 17,650,000 tons of serpentinized dunite.

#### CHEMICAL ANALYSIS<sup>93</sup>

##### SERPENTINIZED DUNITE

Sample	MgO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al, Ti, Cr, (Oxides)	CaO	Ign. Loss
Laurel Creek A-1	42.17	43.92	8.94	1.40	0.00	3.94

#### PETROGRAPHIC ANALYSIS<sup>94</sup>

Sample—LAUREL CREEK B-1. Originally the rock was coarsely crystalline with crystals ranging up to 3 mm. or 4 mm. in diameter. The two principal constituents were olivine and pyroxene (diopside) in the ratio of about 2 to 1. The rock is now highly shattered and altered so that the remaining crystals of olivine and diopside average about 0.1 mm. in diameter.

The olivine appears to have been fairly high in iron content as evidenced by iron oxide occurring with the antigorite.

The principal alteration product is antigorite, which make up 30 to 40 per cent of the rock.

In addition to the minerals discussed above, a small amount of chromite (less than 1 per cent) and a few crystals of talc were observed.

#### P. C. E. VALUE

Sample Laurel Creek B-1 has a P.C.E. value of +36.

To the northeast of the Laurel Creek deposit there occur several additional dunite formations which were

<sup>93</sup> Chemical analysis made by TVA Minerals Testing Laboratory, Norris, Tennessee.

<sup>94</sup> Petrographic analysis made by W. Wurth Kriegel, Department of Ceramic Engineering, University of North Carolina, Raleigh, N. C.

not mapped nor sampled because of their occurrence at points extremely inaccessible from a commercial production standpoint.

South and west of the Laurel Creek deposit the dunite formations in the area have largely been altered into anthophyllite asbestos.

PLATE 31



OLIVINE IS SHIPPED IN OPEN CARS.















